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Burhan et al.

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(54) **ROLLING CUTTER USING PIN, BALL OR EXTRUSION ON THE BIT BODY AS ATTACHMENT METHODS**

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E21B 10/43 (2006.01)
E21B 10/46 (2006.01)
E21B 10/573 (2006.01)

(52) **U.S. Cl.**

CPC ***E21B 10/43*** (2013.01); ***E21B 10/46*** (2013.01); ***E21B 10/573*** (2013.01)

(58) **Field of Classification Search**

CPC E21B 10/43; E21B 10/50; E21B 10/52; E21B 10/55; E21B 10/573; E21B 10/627; E21B 10/633; E21B 10/08

See application file for complete search history.

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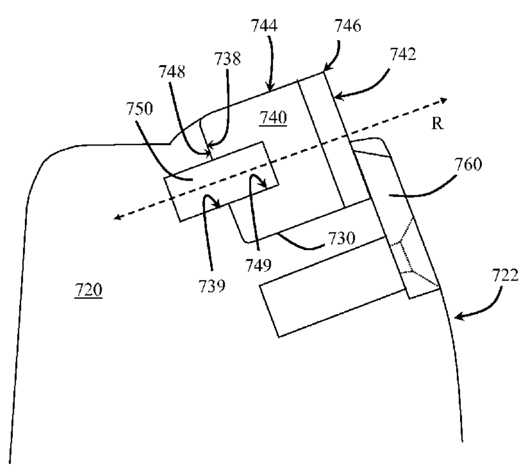
Primary Examiner — Cathleen Hutchins

(57) **ABSTRACT**

A drill bit has a bit body, a plurality of blades extending radially from the bit body, wherein each blade comprises a leading face and a trailing face, a plurality of cutter pockets disposed on the plurality of blades, at least one rolling cutter, wherein each rolling cutter is disposed in one of the cutter pockets, and wherein each rolling cutter comprises a cutting face, a cutting edge, an outer circumferential surface, and a back face. A back retainer is disposed adjacent to the back face, wherein the back retainer protrudes partially into the rolling cutter along a rotational axis of the rolling cutter, and a front retainer is disposed adjacent to the at least one rolling cutter on the leading face of the blade. Each front retainer has a retention end, wherein the retention end is positioned adjacent to a portion of the cutting face of each rolling cutter, and an attachment end, wherein the attachment end is attached to a portion of the blade.

27 Claims, 20 Drawing Sheets



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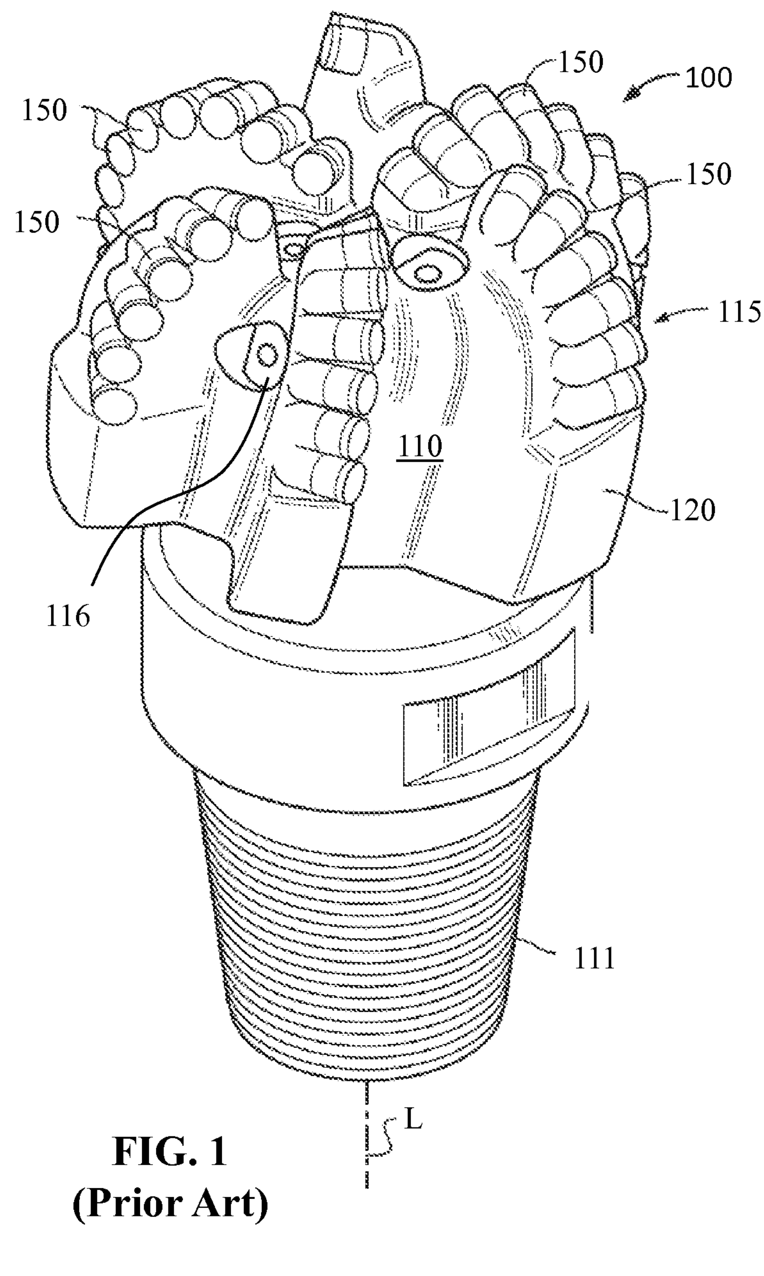

FIG. 1
(Prior Art)

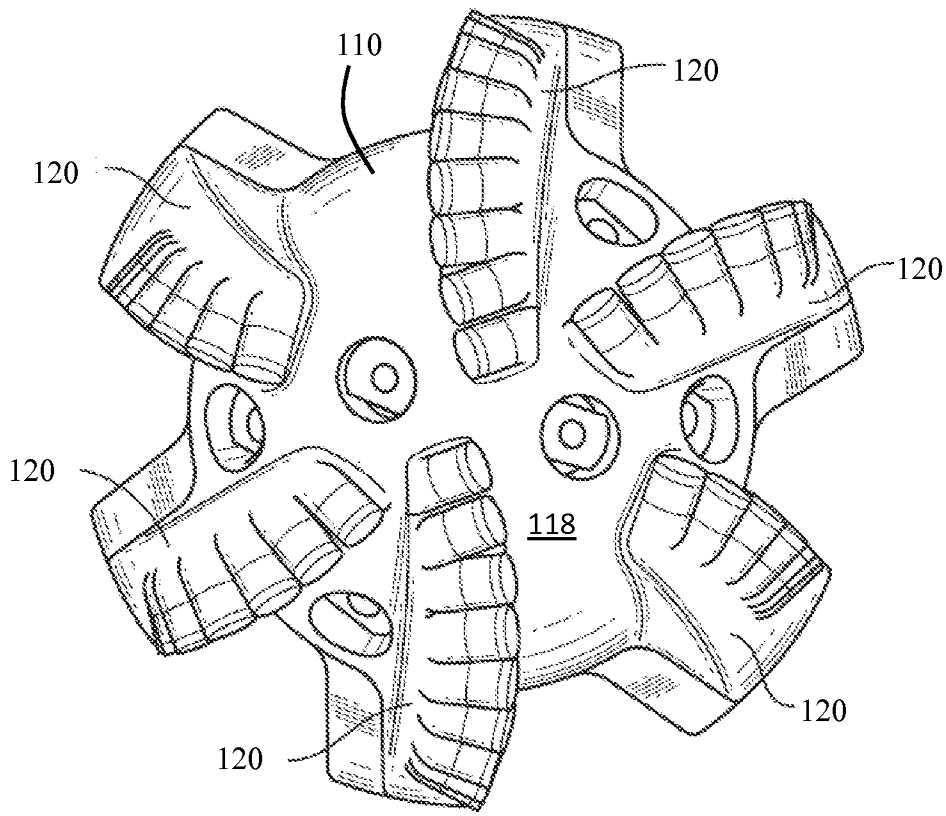

FIG. 2
(Prior Art)

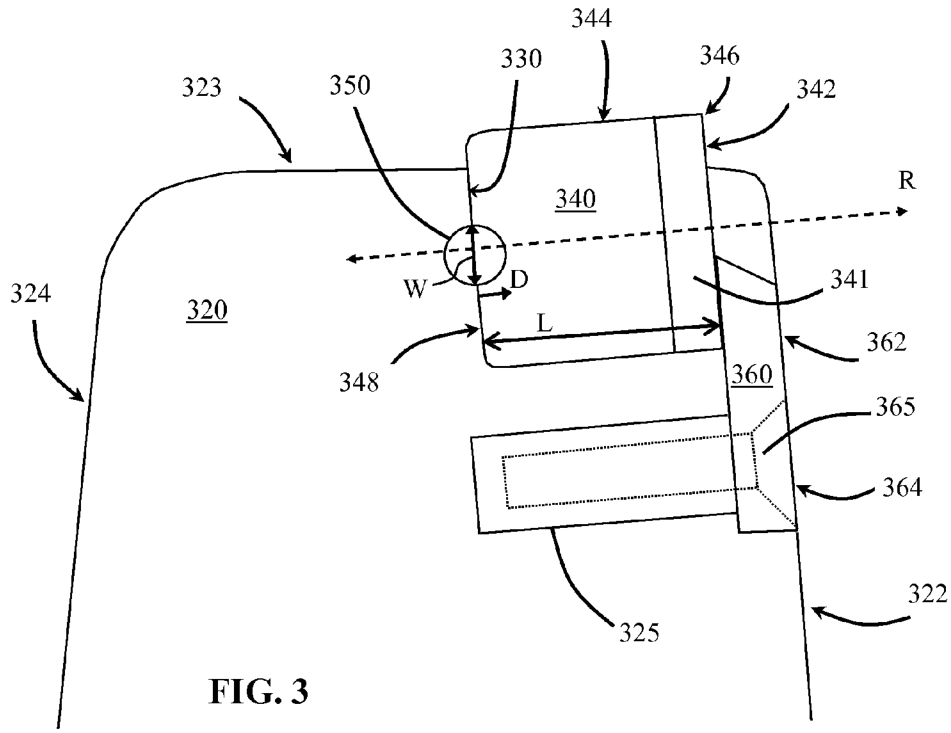
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FIG. 3

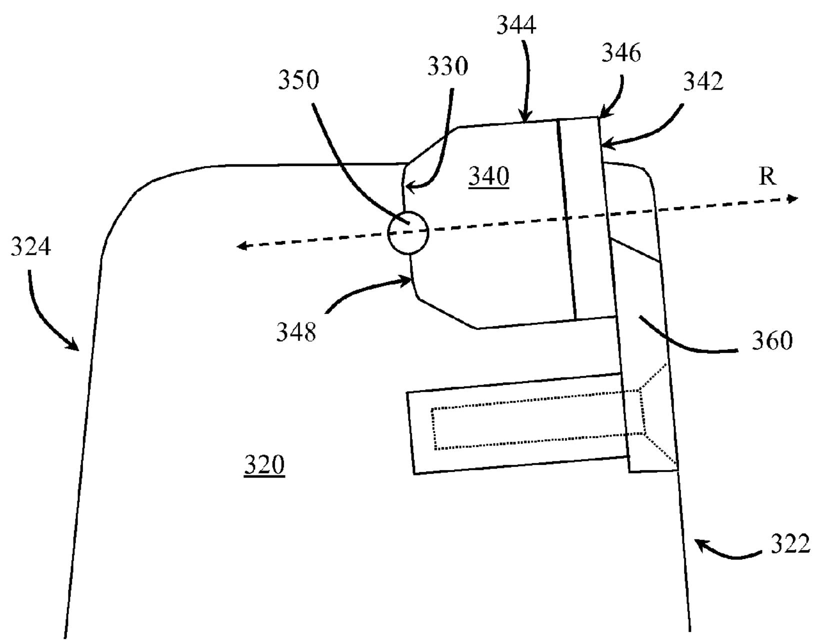
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FIG. 4

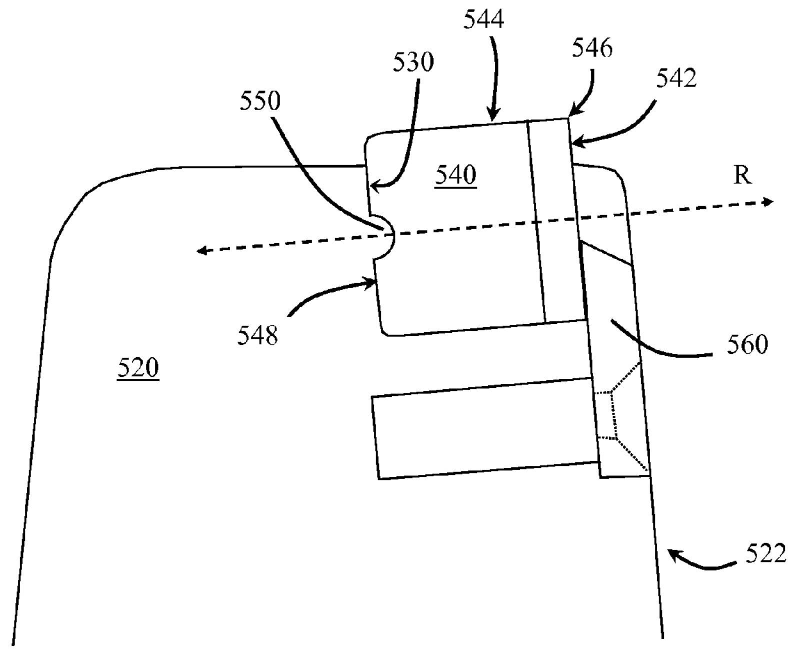
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FIG. 5

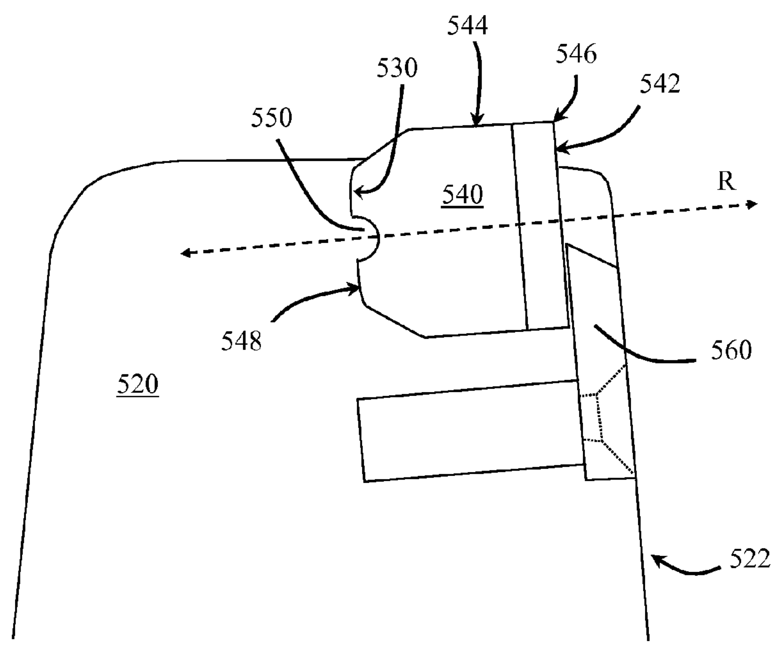
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FIG. 6

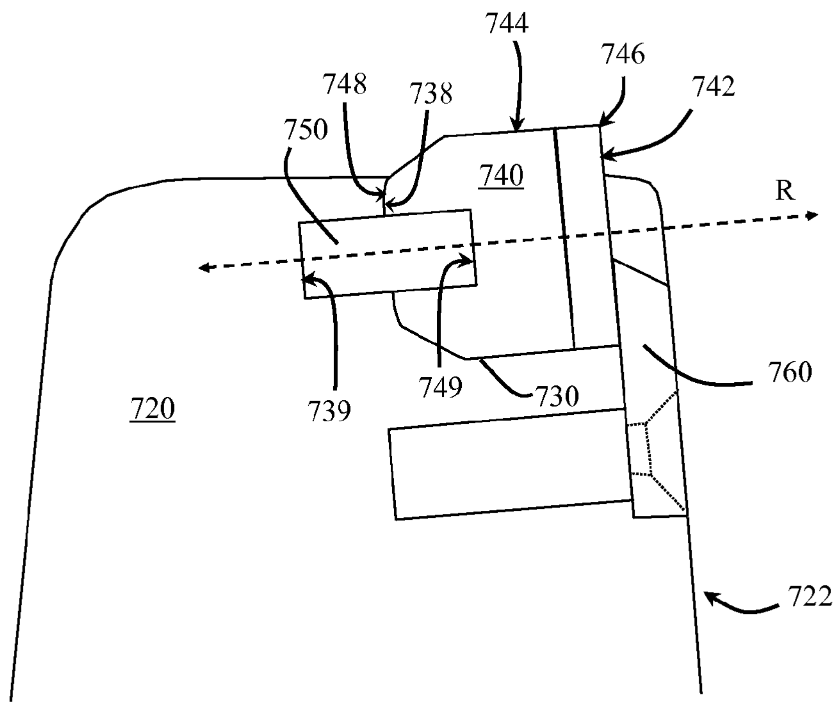
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FIG. 7

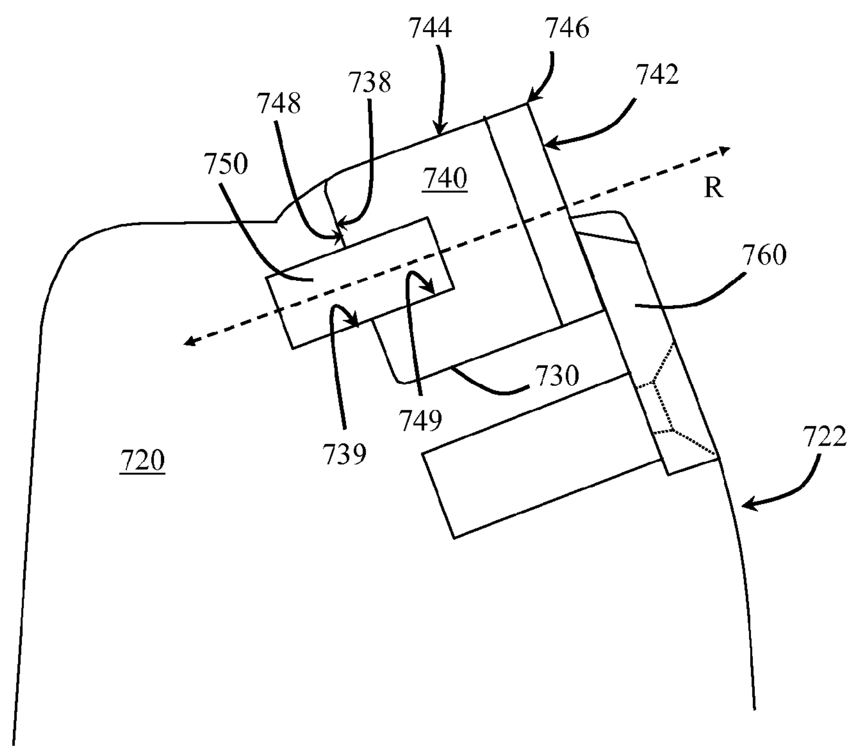
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FIG. 8

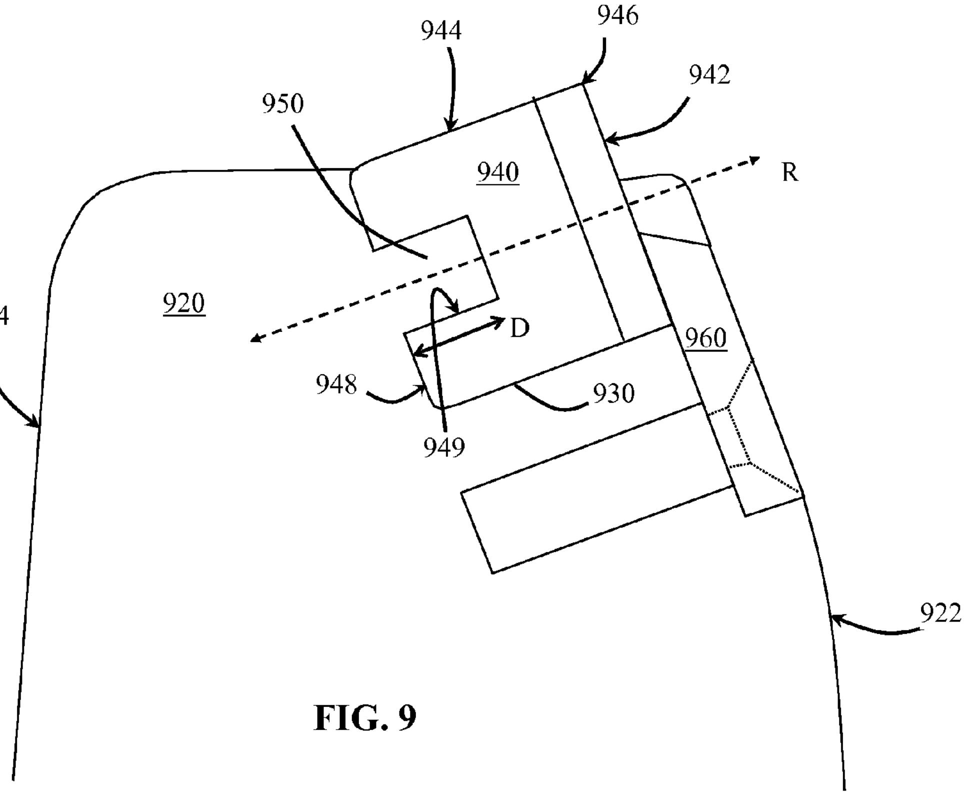

FIG. 9

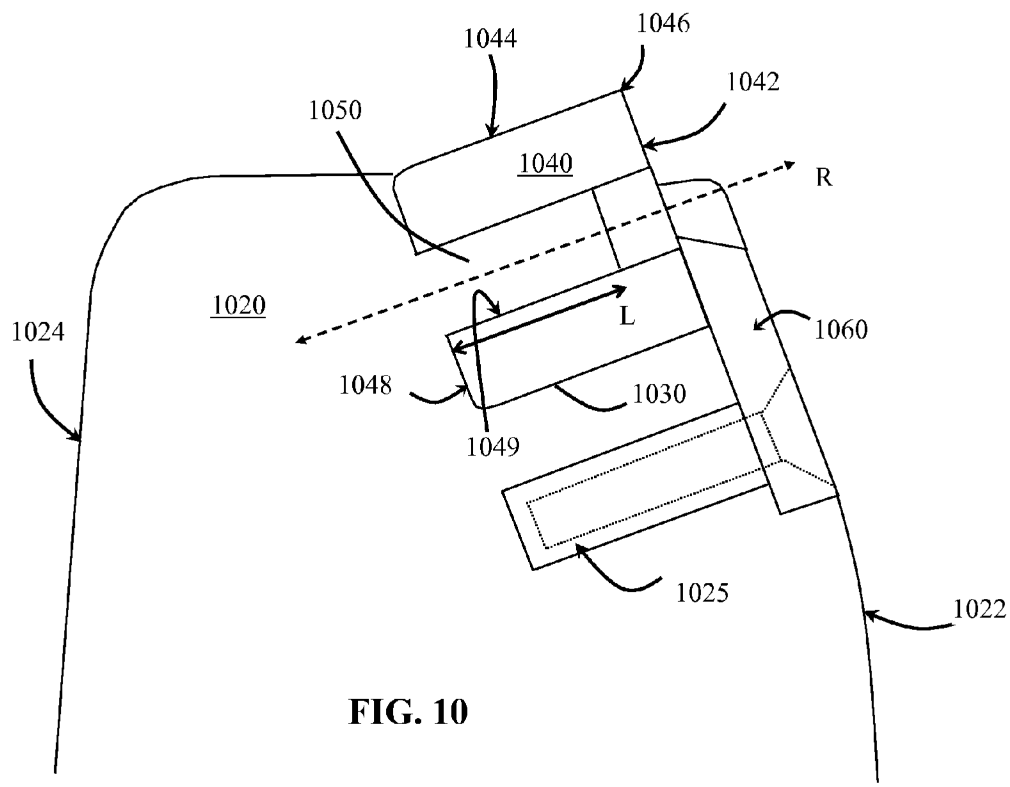
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FIG. 10

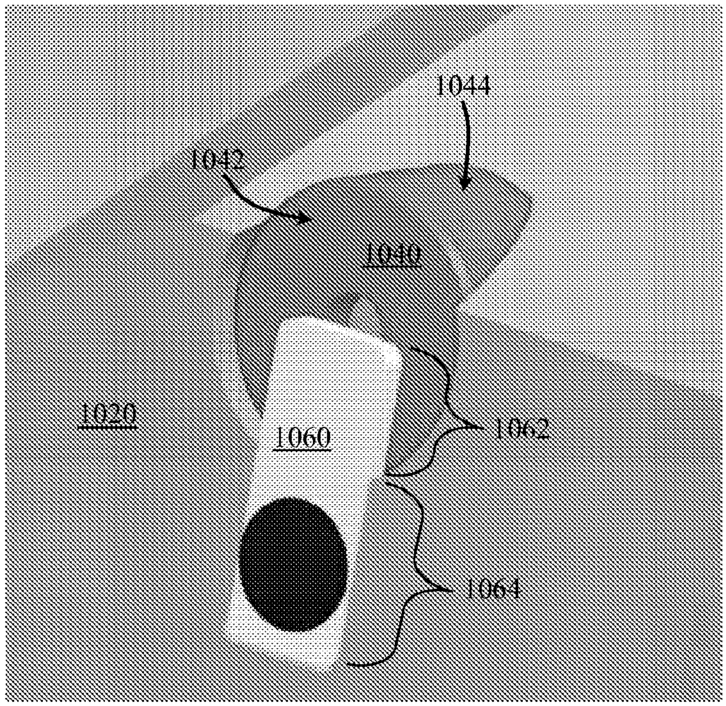
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FIG. 11

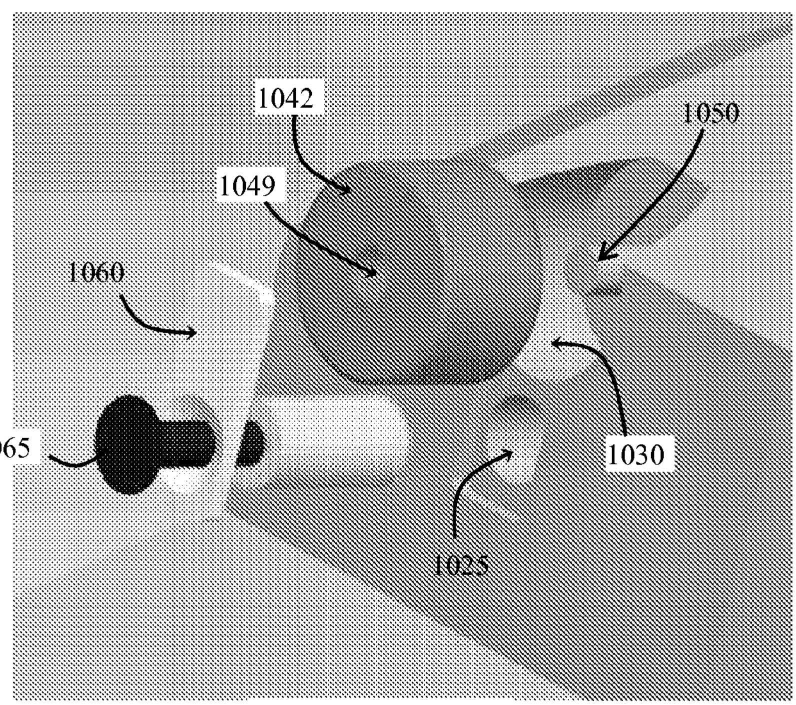
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FIG. 12

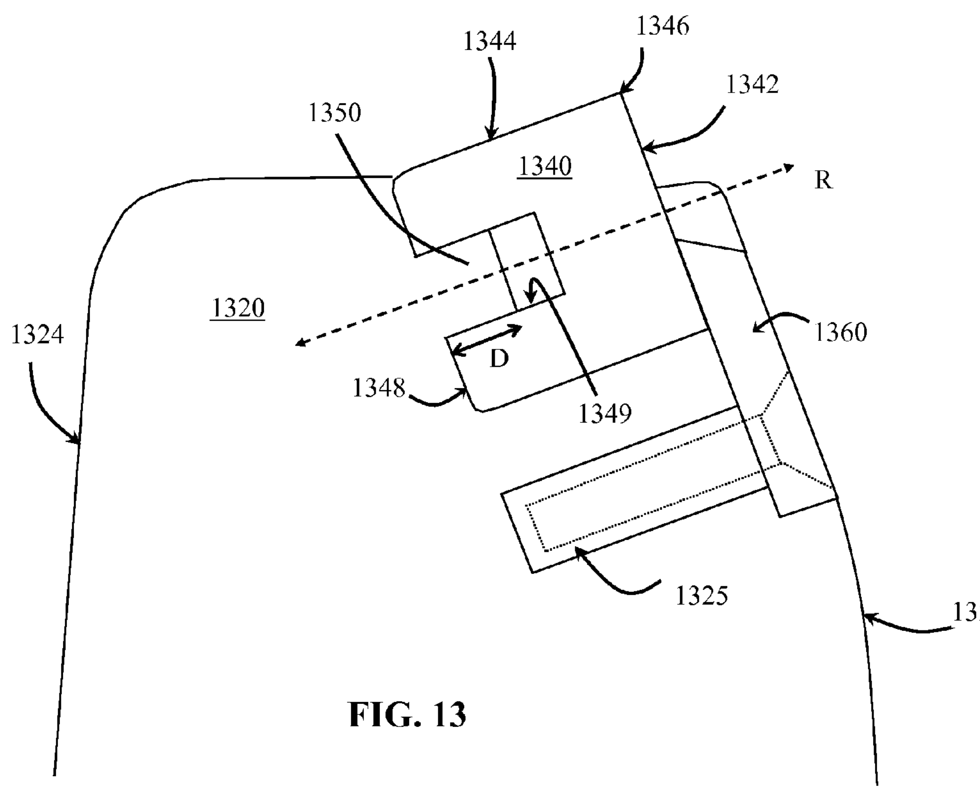
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FIG. 13

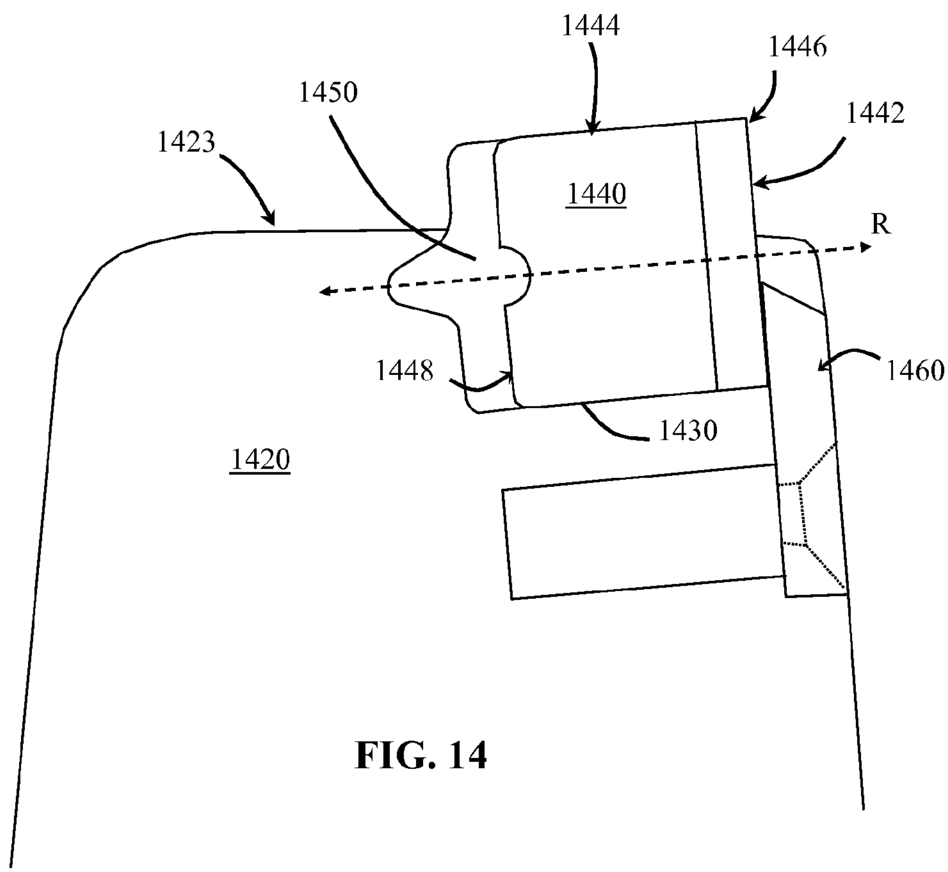

FIG. 14

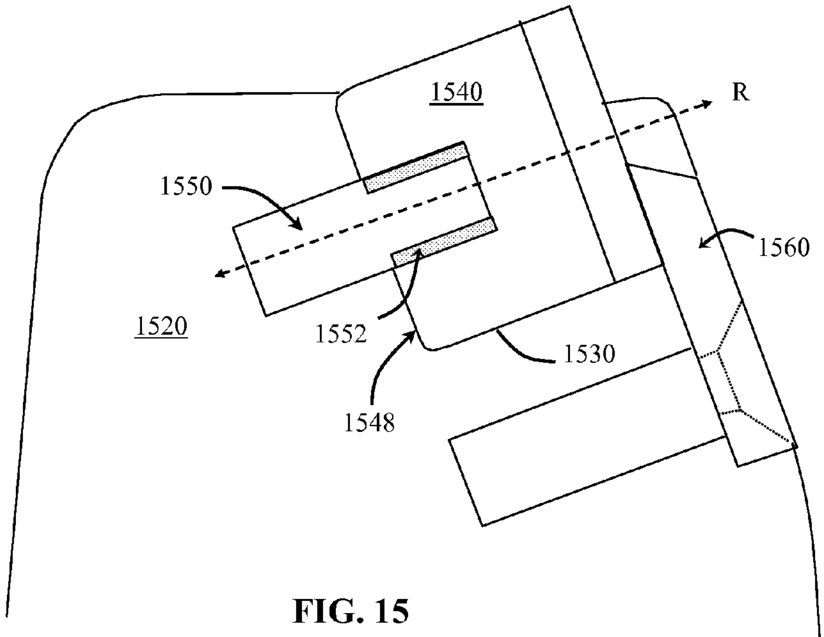
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FIG. 15

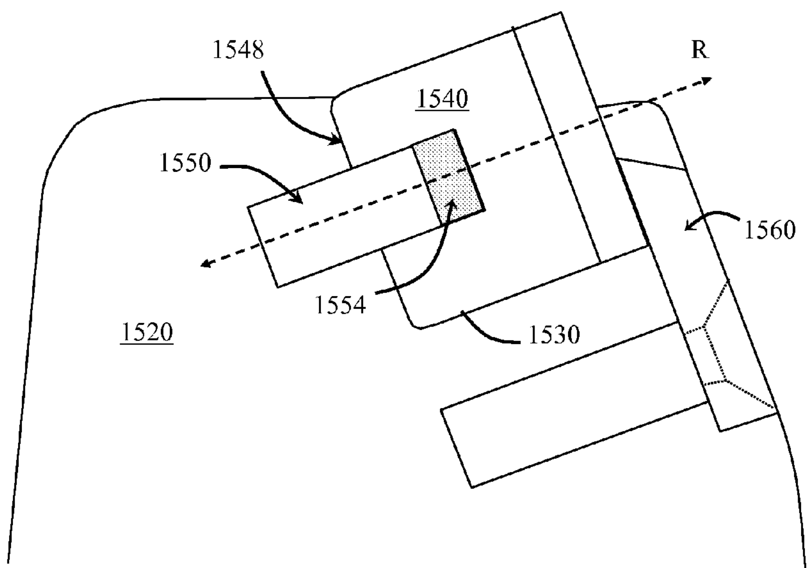
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FIG. 16

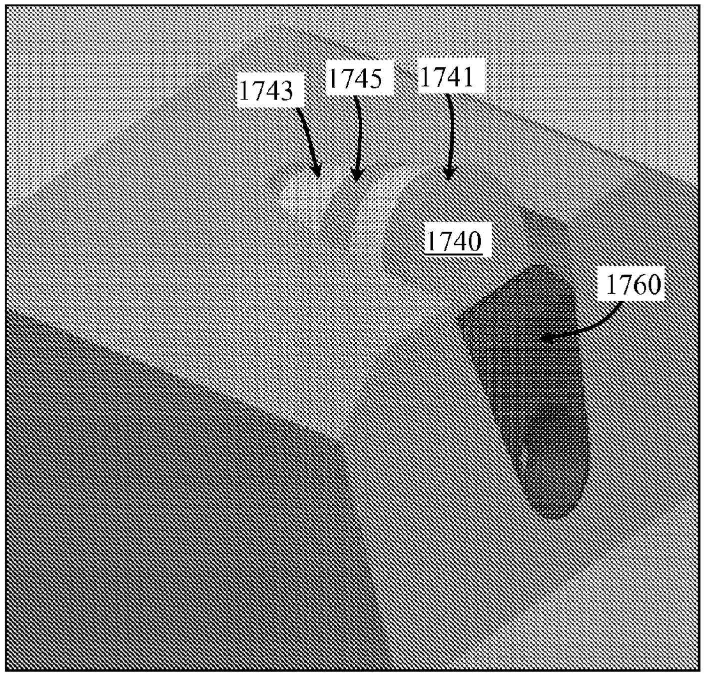

FIG. 17

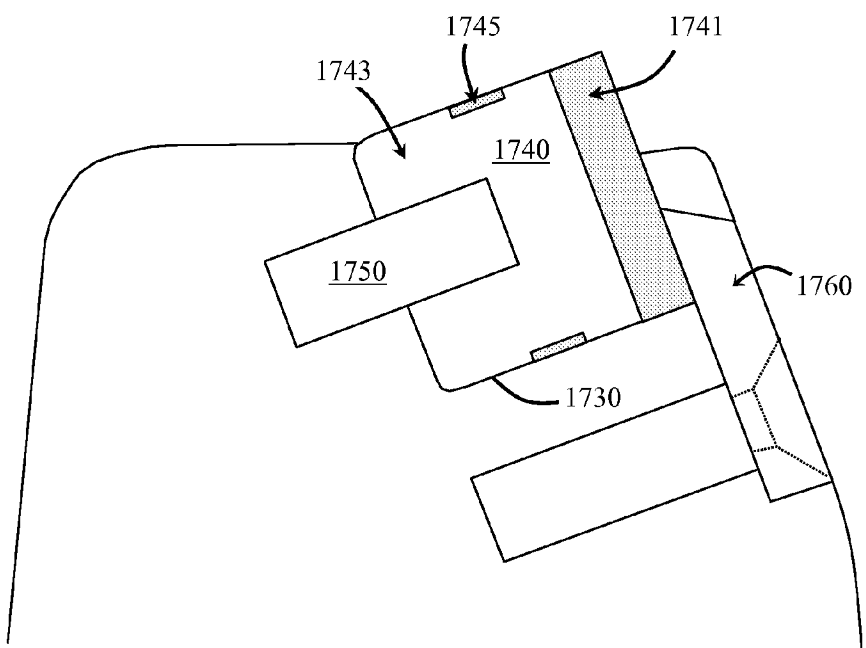

FIG. 18

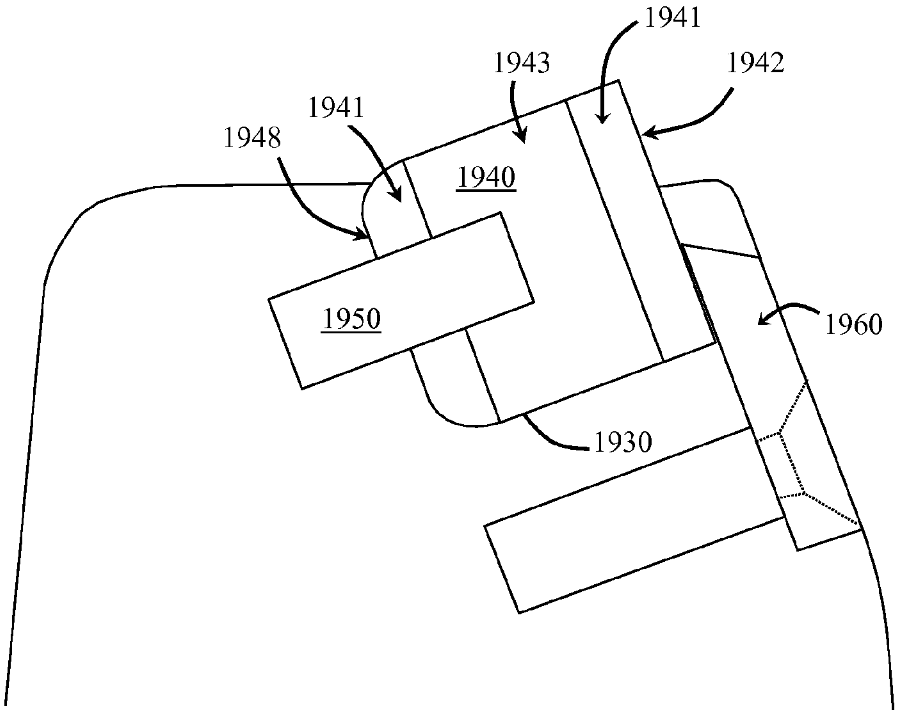

FIG. 19

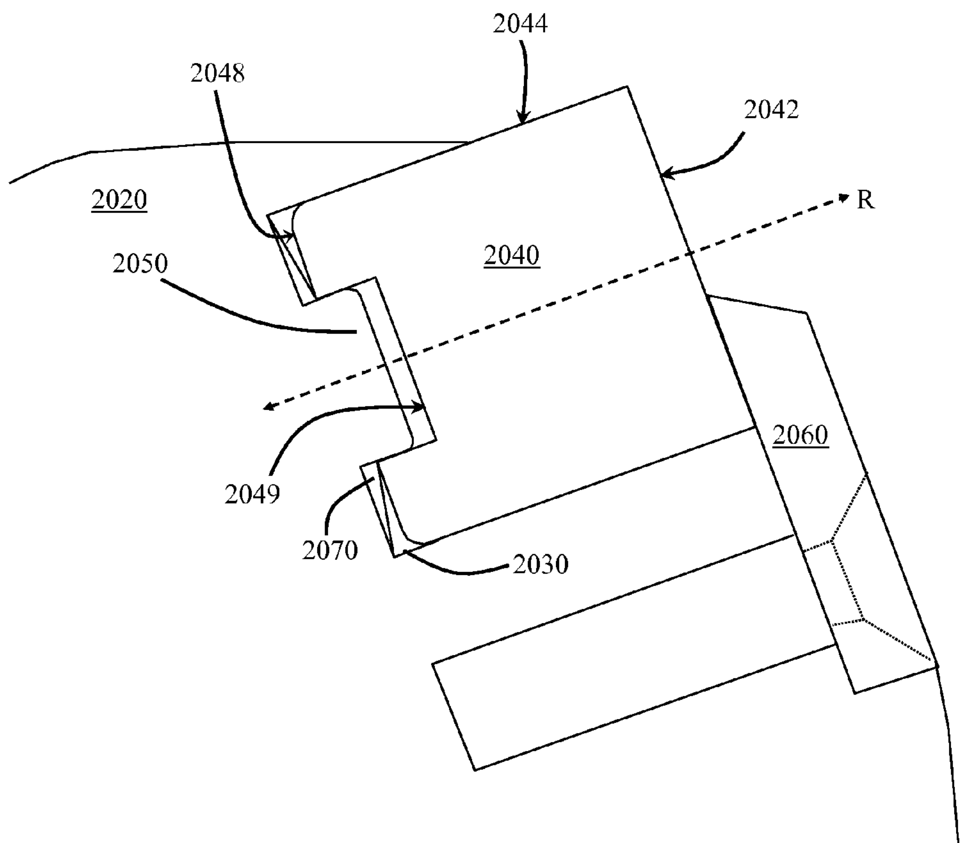

FIG. 20

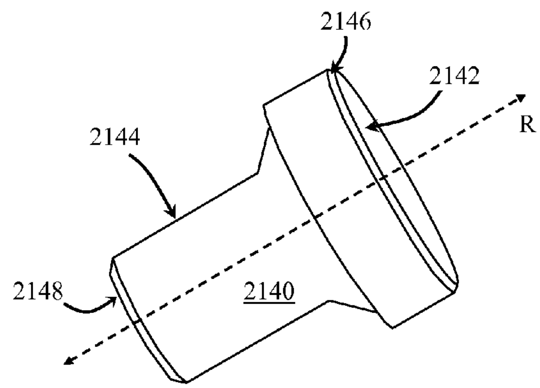

FIG. 21

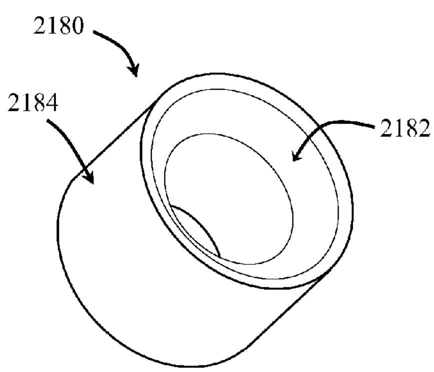

FIG. 22

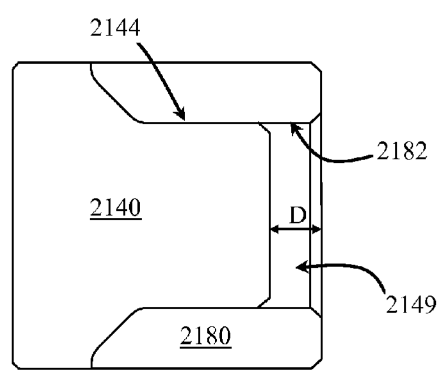

FIG. 23

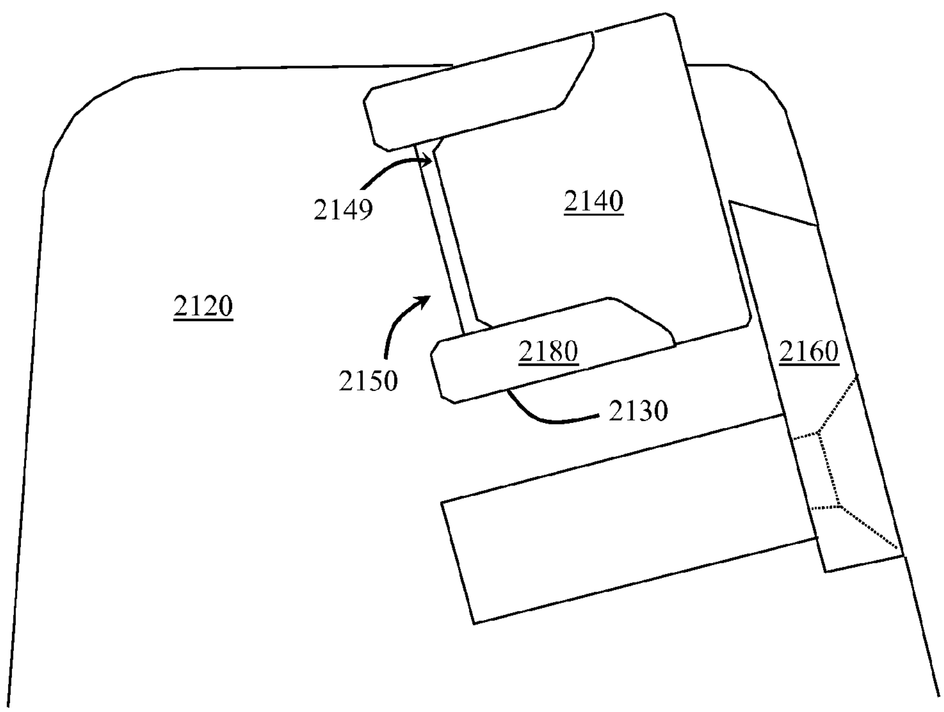

FIG. 24

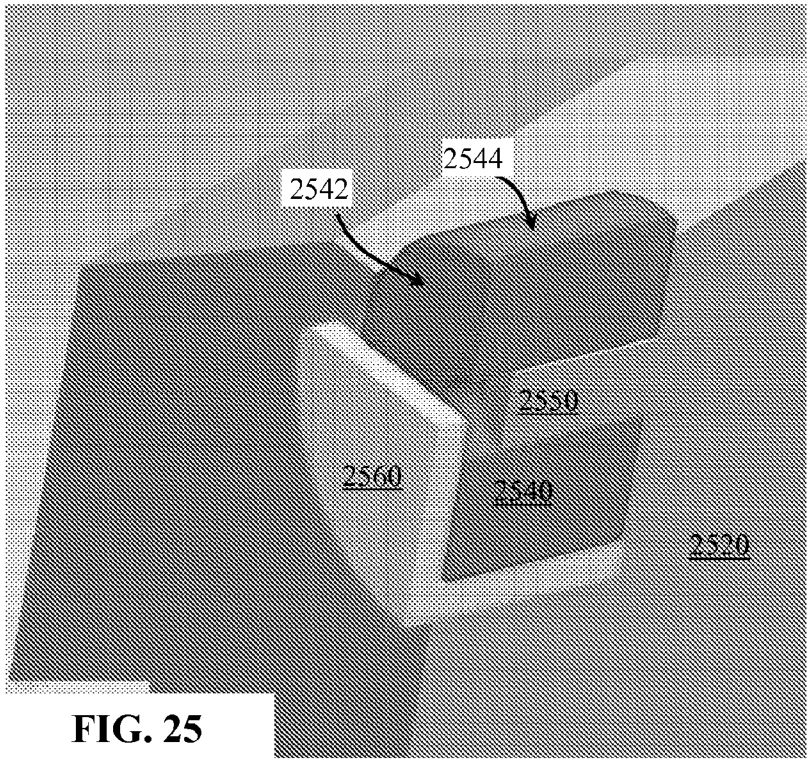
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FIG. 25

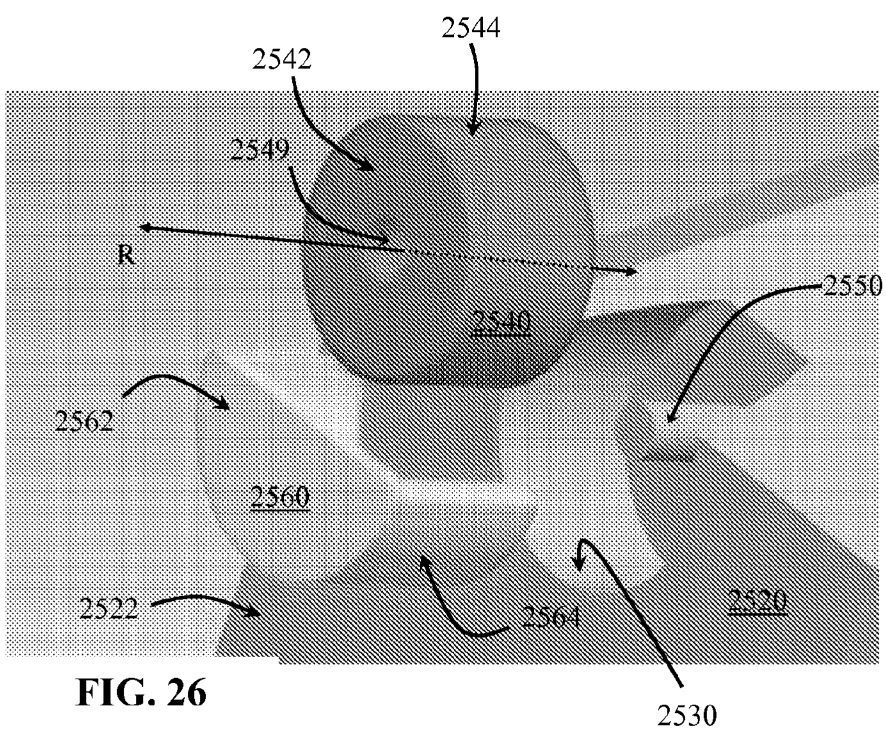
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FIG. 26

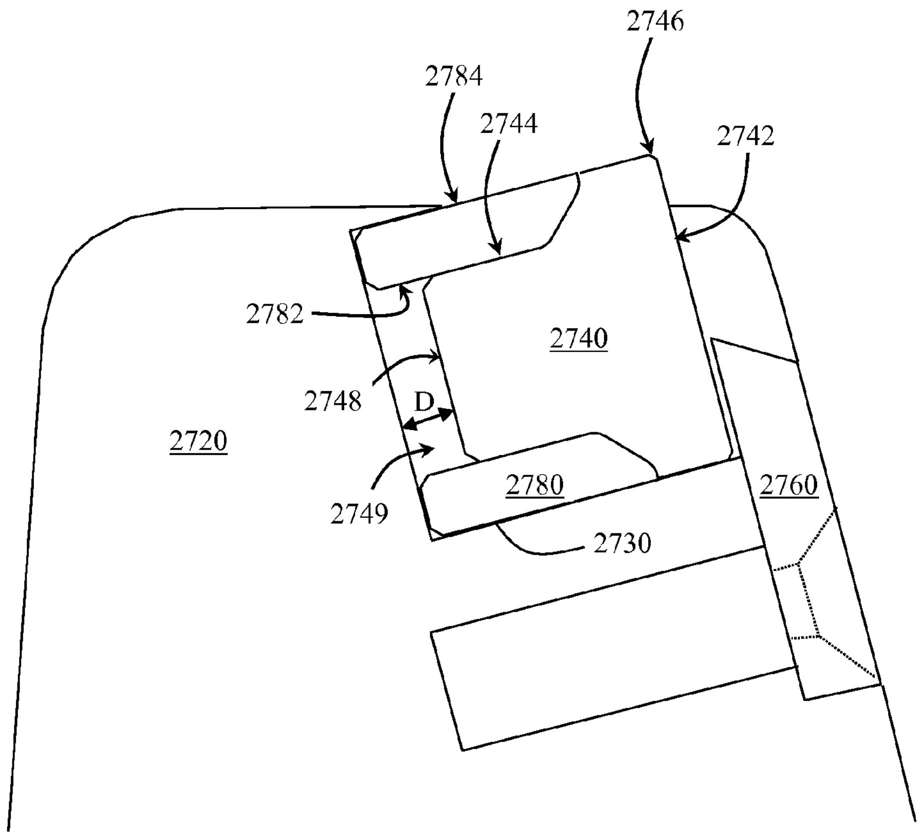

FIG. 27

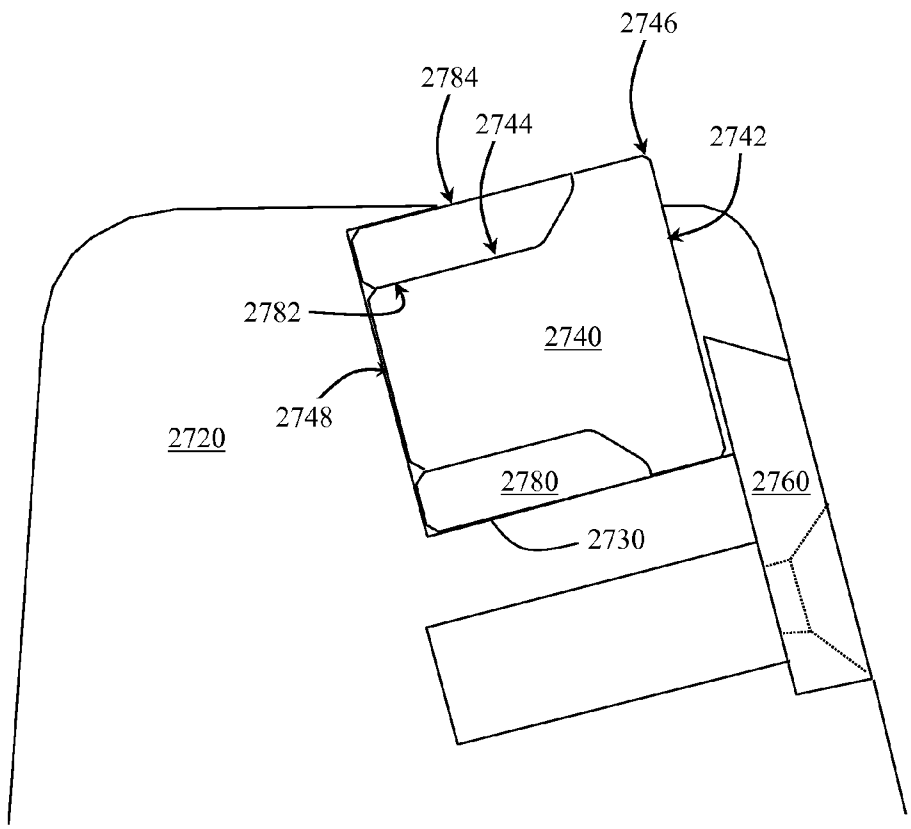

FIG. 28

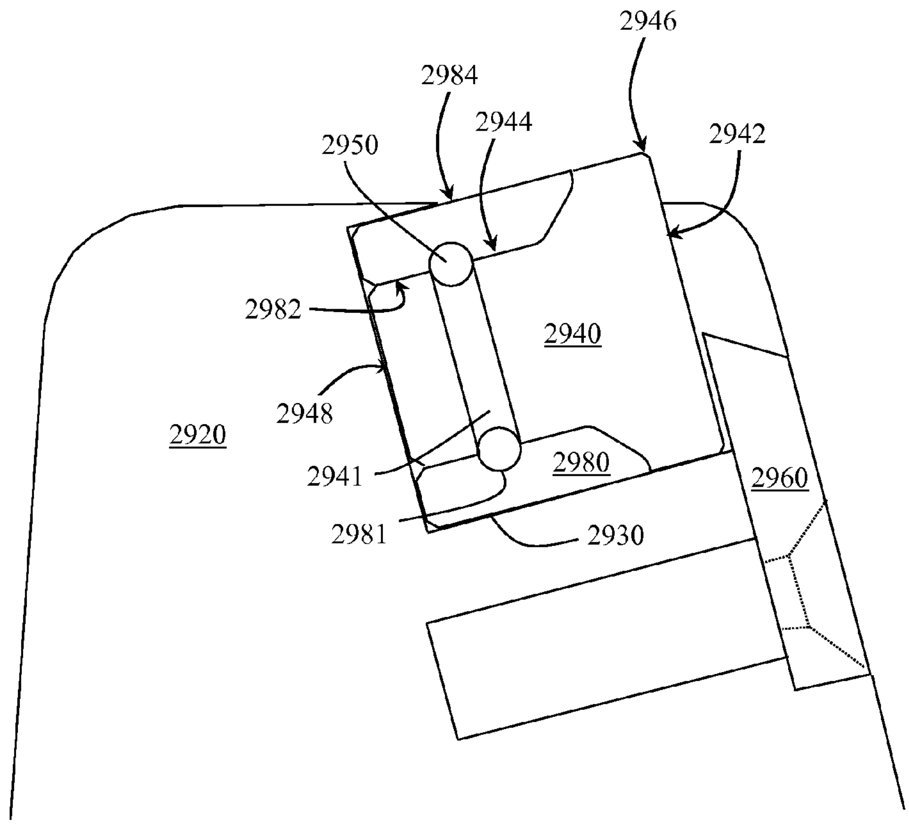
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FIG. 29

ROLLING CUTTER USING PIN, BALL OR EXTRUSION ON THE BIT BODY AS ATTACHMENT METHODS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/566,875 filed Dec. 5, 2011, which is incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

Embodiments disclosed herein relate generally to cutting elements for drill bits or other tools incorporating the same. More specifically, embodiments disclosed herein relate generally to rotatable cutting elements for rotary drill bits.

2. Background Art

Drill bits used to drill wellbores through earth formations generally are made within one of two broad categories of bit structures. Depending on the application/formation to be drilled, the appropriate type of drill bit may be selected based on the cutting action type for the bit and its appropriateness for use in the particular formation. Drill bits in the first category are generally known as "roller cone" bits, which include a bit body having one or more roller cones rotatably mounted to the bit body. The bit body is typically formed from steel or another high strength material. The roller cones are also typically formed from steel or other high strength material and include a plurality of cutting elements disposed at selected positions about the cones. The cutting elements may be formed from the same base material as is the cone. These bits are typically referred to as "milled tooth" bits. Other roller cone bits include "insert" cutting elements that are press (interference) fit into holes formed and/or machined into the roller cones. The inserts may be formed from, for example, tungsten carbide, natural or synthetic diamond, boron nitride, or any one or combination of hard or superhard materials.

Drill bits of the second category are typically referred to as "fixed cutter" or "drag" bits. Drag bits, include bits that have cutting elements attached to the bit body, which may be a steel bit body or a matrix bit body formed from a matrix material such as tungsten carbide surrounded by a binder material. Drag bits may generally be defined as bits that have no moving parts. However, there are different types and methods of forming drag bits that are known in the art. For example, drag bits having abrasive material, such as diamond, impregnated into the surface of the material which forms the bit body are commonly referred to as "impreg" bits. Drag bits having cutting elements made of an ultra hard cutting surface layer or "table" (typically made of polycrystalline diamond material or polycrystalline boron nitride material) deposited onto or otherwise bonded to a substrate are known in the art as polycrystalline diamond compact ("PDC") bits.

PDC bits drill soft formations easily, but they are frequently used to drill moderately hard or abrasive formations. They cut rock formations with a shearing action using small cutters that do not penetrate deeply into the formation. Because the penetration depth is shallow, high rates of penetration are achieved through relatively high bit rotational velocities.

PDC cutters have been used in industrial applications including rock drilling and metal machining for many years. In PDC bits, PDC cutters are received within cutter pockets, which are formed within blades extending from a bit body,

and are typically bonded to the blades by brazing to the inner surfaces of the cutter pockets. The PDC cutters are positioned along the leading edges of the bit body blades so that as the bit body is rotated, the PDC cutters engage and drill the earth formation. In use, high forces may be exerted on the PDC cutters, particularly in the forward-to-rear direction. Additionally, the bit and the PDC cutters may be subjected to substantial abrasive forces. In some instances, impact, vibration and erosive forces have caused drill bit failure due to loss of one or more cutters, or due to breakage of the blades.

In a typical PDC cutter, a compact of polycrystalline diamond ("PCD") (or other superhard material, such as polycrystalline cubic boron nitride) is bonded to a substrate material, which is typically a sintered metal-carbide to form a cutting structure. PCD comprises a polycrystalline mass of diamond grains or crystals that are bonded together to form an integral, tough, high-strength mass or lattice. The resulting PCD structure produces enhanced properties of wear resistance and hardness, making PCD materials extremely useful in aggressive wear and cutting applications where high levels of wear resistance and hardness are desired.

An example of a prior art PDC bit having a plurality of cutters with ultra hard working surfaces is shown in FIGS. **1** and **2**. The drill bit **100** includes a bit body **110** having a threaded upper pin end **111** and a cutting end **115**. The cutting end **115** typically includes a plurality of ribs or blades **120** arranged about the rotational axis L (also referred to as the longitudinal or central axis) of the drill bit and extending radially outward from the bit body **110**. Cutting elements, or cutters, **150** are embedded in the blades **120** at predetermined angular orientations and radial locations relative to a working surface and with a desired back rake angle and side rake angle against a formation to be drilled.

A plurality of orifices **116** are positioned on the bit body **110** in the areas between the blades **120**, which may be referred to as "gaps" or "fluid courses." The orifices **116** are commonly adapted to accept nozzles. The orifices **116** allow drilling fluid to be discharged through the bit in selected directions and at selected rates of flow between the blades **120** for lubricating and cooling the drill bit **100**, the blades **120** and the cutters **150**. The drilling fluid also cleans and removes the cuttings as the drill bit **100** rotates and penetrates the geological formation. Without proper flow characteristics, insufficient cooling of the cutters **150** may result in cutter failure during drilling operations. The fluid courses are positioned to provide additional flow channels for drilling fluid and to provide a passage for formation cuttings to travel past the drill bit **100** toward the surface of a wellbore (not shown).

Referring to FIG. **2**, a top view of a prior art PDC bit is shown. The cutting face **118** of the bit shown includes a plurality of blades **120**, wherein each blade has a leading side **122** facing the direction of bit rotation, a trailing side **124** (opposite from the leading side), and a top side **126**. Each blade includes a plurality of cutting elements or cutters generally disposed radially from the center of cutting face **118** to generally form rows. Certain cutters, although at differing axial positions, may occupy radial positions that are in similar radial position to other cutters on other blades.

Cutters are conventionally attached to a drill bit or other downhole tool by a brazing process. In the brazing process, a braze material is positioned between the cutter and the cutter pocket. The material is melted and, upon subsequent solidification, bonds (attaches) the cutter in the cutter pocket. Selection of braze materials depends on their respective melting temperatures, to avoid excessive thermal exposure (and thermal damage) to the diamond layer prior to the bit (and cutter) even being used in a drilling operation. Specifically, alloys suitable for brazing cutting elements with diamond layers thereon have been limited to only a couple of alloys which offer low enough brazing temperatures to avoid damage to the diamond layer and high enough braze strength to retain cutting elements on drill bits.

Cracking (and/or formation of micro-cracks) in the bit body can also occur during the cutter brazing process in the area surrounding the cutter pockets. The formation and propagation of cracks in the matrix body during the drilling process may result in the loss of one or more PDC cutters. A lost cutter may abrade against the bit, causing further accelerated bit damage. FIG. **16** illustrates such cracking that can occur in a bit body using a conventional cutter.

A significant factor in determining the longevity of PDC cutters is the exposure of the cutter to heat. Conventional polycrystalline diamond is stable at temperatures of up to 700-750° C. in air, above which observed increases in temperature may result in permanent damage to and structural failure of polycrystalline diamond. This deterioration in polycrystalline diamond is due to the significant difference in the coefficient of thermal expansion of the binder material, cobalt, as compared to diamond. Upon heating of polycrystalline diamond, the cobalt and the diamond lattice will expand at different rates, which may cause cracks to form in the diamond lattice structure and result in deterioration of the polycrystalline diamond. Damage may also be due to graphite formation at diamond-diamond necks leading to loss of microstructural integrity and strength loss, at extremely high temperatures.

Exposure to heat (through brazing or through frictional heat generated from the contact of the cutter with the formation) can cause thermal damage to the diamond table and eventually result in the formation of cracks (due to differences in thermal expansion coefficients) which can lead to spalling of the polycrystalline diamond layer, delamination between the polycrystalline diamond and substrate, and conversion of the diamond back into graphite causing rapid abrasive wear. As a cutting element contacts the formation, a wear flat develops and frictional heat is induced. As the cutting element is continued to be used, the wear flat will increase in size and further induce frictional heat. The heat may build-up that may cause failure of the cutting element due to thermal missmatch between diamond and catalyst discussed above. This is particularly true for cutters that are immovably attached to the drill bit, as conventional in the art.

Accordingly, there exists a continuing need to develop ways to extend the life of a cutting element.

SUMMARY

This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

In one aspect, embodiments of the present disclosure relate to a drill bit having a bit body, a plurality of blades extending radially from the bit body, wherein each blade comprises a leading face and a trailing face, a plurality of cutter pockets disposed on the plurality of blades, at least one rolling cutter, wherein each rolling cutter is disposed in one of the cutter pockets, and wherein each rolling cutter comprises a cutting face, a cutting edge, an outer circumferential surface, and a back face, a back retainer disposed adjacent to the back face, wherein the back retainer protrudes partially into the rolling cutter along a rotational axis of the rolling cutter, and a front retainer disposed adjacent to the at least one rolling cutter on the leading face of the blade. Each front retainer has a retention end, wherein the retention end is positioned adjacent to a portion of the cutting face of each rolling cutter and an attachment end, wherein the attachment end is attached to a portion of the blade.

In another aspect, embodiments of the present disclosure relate to a method of manufacturing a drill bit that includes forming a bit body comprising a threaded pin end and a cutting end, wherein at least one blade is formed on the cutting end, and wherein the blade has a plurality of cutter pockets formed therein, placing a rolling cutter into at least one of the plurality of cutter pockets, adjacent to a back retainer, wherein the rolling cutter comprises a substrate and a cutting face, and attaching an attachment end of a front retainer to a portion of the blade, such that a retention end of the front retainer covers a portion of the cutting face.

Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** shows a side view of a conventional drag bit.

FIG. **2** shows a top view of a conventional drag bit.

FIG. **3** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **4** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **5** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **6** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **7** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **8** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **9** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **10-12** show a cross-sectional view and perspective views, respectively, of a rolling cutter according to embodiments of the present disclosure.

FIG. **13** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **14** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **15** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **16** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIGS. **17** and **18** show a perspective view and a cross-sectional view, respectively, of a rolling cutter according to embodiments of the present disclosure.

FIG. **19** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **20** shows a cross-sectional view of a rolling cutter according to embodiments of the present disclosure.

FIG. **21** shows a perspective view of a rolling cutter according to embodiments of the present disclosure.

FIG. **22** shows a perspective view of an outer shell according to embodiments of the present disclosure.

FIGS. **23** and **24** show cross-sectional views of a rolling cutter and outer shell according to embodiments of the present disclosure.

FIGS. **25** and **26** show a cross-sectional view and a perspective view of a rolling cutter according to embodiments of the present disclosure.

FIG. **27** shows a cross-sectional view of a rolling cutter assembly according to embodiments of the present disclosure.

FIG. **28** shows a cross-sectional view of a rolling cutter assembly according to embodiments of the present disclosure.

FIG. **29** shows a cross-sectional view of a rolling cutter assembly according to embodiments of the present disclosure.

DETAILED DESCRIPTION

Drill bits according to embodiments of the present disclosure and methods for forming such drill bits are described below. According to some embodiments of the present disclosure, a drill bit may have a front retainer and a back retainer positioned adjacent to a rolling cutter. Rolling cutters of the present disclosure may be used on downhole cutting tools including, for example, drag bits and hybrid drill bits.

A rolling cutter, as referred to herein, is a cutting element having at least one surface that may rotate within a cutter pocket as the cutting element contacts the drilling formation. As the cutting element contacts the formation, shearing may allow a portion of the cutting element to rotate around a cutting element axis extending through a central plane of the cutting element. Rolling cutters according to the present disclosure are retained within the cutter pocket by a front retainer and a back retainer. As used herein, a front retainer is a component separate from the bit that is attached to the bit, adjacent to the cutting face of a rolling cutter to prevent the rolling cutter from coming out of the cutter pocket. In a particular embodiment, the front retainers of the present disclosure may be attached or coupled with the bit body in a position radially exterior to the rolling cutter. As used herein, a back retainer is a component separate from or integral with the bit, adjacent to the back face of a rolling cutter to prevent the rolling cutter from coming out of the cutter pocket. A rolling cutter and a corresponding front retainer and back retainer together may be referred to as a rolling cutter assembly.

Rotation of a portion of the cutting element may allow a cutting surface to cut formation using the entire outer edge (i.e., the entire circumferential edge) of the cutting surface, rather than the same section of the outer edge, as provided by the prior art. The entire edge of the cutting element may contact the formation, generating more uniform cutting element edge wear, thereby preventing for formation of a local wear flat area. Because the edge wear is more uniform, the cutting element may not wear as quickly, thereby having a longer downhole life, and thus increasing the overall efficiency of the drilling operation.

Rotatable cutting elements may also prevent or at least reduce high temperatures typically generated by fixed cutters during drilling. Because the cutting surface of prior art cutting elements is constantly contacting formation, heat may build-up that may cause failure of the cutting element due to fracture. Embodiments in accordance with the present disclosure may avoid this heat build-up because the edge contacting the formation changes. By decreasing the thermal and mechanical load experienced by the cutting surface of the cutting element, cutting element life may be increased, thereby allowing more efficient drilling.

Embodiments of the present disclosure may utilize back retainers and front retainers to retain rolling cutters to cutter pockets while also allowing the rolling cutters to rotate within the cutter pockets. Advantageously, means of retaining a rolling cutter in a cutter pocket described herein may allow for increased rolling cutter exposure (less cutter pocket coverage of the rolling cutter) and improved cleaning of the cutter pocket.

Drill bits according to embodiments of the present disclosure may include a bit body and a plurality of blades extending radially from the bit body, wherein the blades may have a plurality of cutter pockets disposed thereon. A rolling cutter may be retained within one or more cutter pockets using a back retainer and a front retainer according to embodiments of the present disclosure. For example, referring to FIGS. **3** and **4**, cross-sectional views of a rolling cutter according to embodiments of the present disclosure are shown disposed within a cutter pocket on a bit blade. As shown in FIG. **3**, a blade **320** may have a leading face **322**, a top face **323** and a trailing face **324**, wherein the leading face **322** faces in the direction of blade rotation. A cutter pocket **330** may be formed in the blade **320** at the leading face **322** of the blade, wherein a cutter pocket side surface intersects at the leading face **322** and top face **323** of the blade **320**, and a cutter pocket back surface intersects the top face **323** of the blade **320**. A rolling cutter **340** may be disposed in the cutter pocket **330**, wherein the rolling cutter **340** has a cutting face **342**, an outer circumferential surface **344**, a cutting edge **346** formed at the intersection of the cutting face **342** and the outer circumferential surface **344**, and a back face **348**. Further, as shown, the rolling cutter **340** may have an abrasive material table **341**, such as a polycrystalline diamond table, form the cutting face **342** of the rolling cutter.

A back retainer **350** may be disposed in the cutter pocket **330** adjacent to the back face **348** of the rolling cutter **340**, wherein the back retainer **350** protrudes partially into the rolling cutter **340** along a rotational axis R of the rolling cutter **340**. The back retainer **350** may have a width W with an upper limit of 75% of the rolling cutter diameter. In other embodiments, a back retainer may have a width with an upper limit of 50% of the rolling cutter diameter. The width W of the back retainer depends on the material used to form the back retainer and the rolling cutter, but may have a lower limit of 10% of the rolling cutter diameter. According to embodiments disclosed herein, a back retainer may have a width with an upper limit of any of 75%, 50% and 25% of the rolling cutter diameter and a lower limit of any of 10%, 15% and 20% of the rolling cutter diameter. Additionally, the back retainer **350** may extend into the rolling cutter **340** a distance D of at least 10 percent of the length L of the rolling cutter **340** and up to a distance to an abrasive material table or to the rolling cutter cutting face (i.e., the entire length of the rolling cutter). Further, in embodiments having a back retainer that is a separate component from the blade, the back retainer may also extend a distance into the blade. For example, as shown in FIGS. **3** and **4**, the back retainer **350** is disposed between the back face **348** of the rolling cutter **340** and the back surface of the cutter pocket **330**, wherein the back retainer **350** protrudes partially into the rolling cutter **340** along the rotational axis R and extends partially into the blade **320**. As shown, the back retainer **350** is a ball. However, according to other embodiments, a back retainer may have a cylindrical shape (such as a pin) or may have an irregular shape that protrudes into the blade and/or rolling cutter along the rotational axis of the rolling cutter.

A front retainer **360** may be disposed adjacent to the rolling cutter **340** on the leading face **322** of the blade **320**. The front retainer **360** has a retention end **362** positioned adjacent to a portion of the cutting face **342** of the rolling cutter **340**, and an attachment end **364** attached to a portion of the blade **320**. As shown, the attachment end **364** of the front retainer **360** may be attached to a portion of the leading face **322** of the blade

320 by using a screw **365** or other like fastener. Specifically, the screw **365** may be inserted through a hole in the attachment end **364** of the front retainer **360** and into a threaded cavity **325** formed within the leading face **322** of the blade **320** below the cutter pocket **330**. According to some embodiments, a threaded cavity may include a steel nut that has been infiltrated into the bit, wherein threads may be machined in the inside of the nut before or after infiltration, or just machined into the bit if the bit material is machinable. If threads are machined into the nut before infiltration, materials such as graphite may be used to protect the structure of the hole and threads during the infiltration process.

Front retainers of the present disclosure may include at least two functional portions: an attachment end, which acts as an attachment between the front retainer and the bit, and a retention end, which is located adjacent to the cutting face of a rolling cutter to retain the rolling cutter within a cutter pocket. A front retainer may be formed from various materials and have various shapes and sizes to prevent the rolling cutter from coming out of a cutter pocket formed in the bit. For example, a front retainer may be formed of a carbide material, such as tungsten carbide. Additionally, some embodiments of front retainers may have diamond, such as on the portion of the front retainer that is proximate to the cutting face of a rolling cutter once assembled.

For example, FIGS. **25-26** show another embodiment of a front retainer that may be used in conjunction with a back retainer to retain a rolling cutter within a cutter pocket. As shown, a rolling cutter **2540** may be retained within a cutter pocket **2530** formed at the leading face **2522** of a blade **2520** using a back retainer **2550** and a front retainer **2560**, wherein the back retainer **2550** is a pin and integrally formed with the blade **2520**. The rolling cutter **2540** has a cutting face **2542**, an outer circumferential surface **2544** and a back face. The back retainer **2550** protrudes into a hole **2549** formed in the rolling cutter **2540** along a rotational axis R of the rolling cutter **2540**, such that the rolling cutter **2540** may rotate about the back retainer **2550**. The front retainer **2560** has a retention end **2562** positioned adjacent to a portion of the cutting face **2542** of the rolling cutter **2540**, and an attachment end **2564** attached to a portion of the blade **2520**. As shown, the attachment end **2564** of the front retainer **60** may form a portion of the cutter pocket **2530**, wherein the rolling cutter **2540** may interface with and rotate within the attachment end **2564** of the front retainer **2560**. The attachment end **2564** may be attached to a portion of the leading face **2522** of the blade **2520** by brazing. Other embodiments of front retainers that may be used to retain the rolling cutter within the cutter pocket may be found in U.S. application Ser. No. 13/152,626 also published as U.S. Publication No. 2011/0297454, which is hereby incorporated by reference in its entirety.

Referring again to FIG. **4**, a cross-sectional view of another rolling cutter according to embodiments of the present disclosure disposed within a cutter pocket on a bit blade. As shown, a blade **320** may have a leading face **322** and a trailing face **324**, wherein the leading face **322** faces in the direction of blade rotation. A rolling cutter **340** may be disposed in a cutter pocket **330** formed at the leading face **322** of the blade. The rolling cutter **340** has a cutting face **342**, an outer circumferential surface **344**, a cutting edge **346** formed at the intersection of the cutting face **342** and the outer circumferential surface **344**, and a back face **348**. Further, as shown, the rolling cutter **340** may have an abrasive material table **341**, such as a polycrystalline diamond table, form the cutting face **342** of the rolling cutter. A back retainer **350** may be disposed adjacent to the back face **348** of the rolling cutter **340**, wherein the back retainer **350** protrudes partially into the rolling cutter **340** along a rotational axis R of the rolling cutter **340**, and a front retainer **360** may be disposed adjacent to the rolling cutter **340** on the leading face **322** of the blade **320**.

The cutting edge (the intersection of the cutting face and the outer circumferential surface) as shown in FIG. **4** forms a substantially perpendicular intersection. However, according to some embodiments, the cutting edge may have a bevel formed at the intersection of the cutting face and the outer circumferential surface. Likewise, some embodiments of rolling cutters may have a bevel formed at the intersection of the back face and the outer circumferential surface. According to other embodiments, such as shown in FIG. **4**, the back face **348** of the rolling cutter **340** may have a conical shape, wherein the intersection between the back face and outer circumferential surface forms an obtuse angle. In some embodiments of rolling cutters having a conical shaped back face, the transition from the back face to the outer circumferential surface may be gradual and continuous rather than forming an intersection angle. Other embodiments of rolling cutters having a conical shaped back face are described in U.S. patent application Ser. No. 13/456,352 also published as U.S. Publication No. 2012/0273280, which is hereby incorporated by reference. The cutter pocket **330** may have a shape substantially corresponding to the rolling cutter back face **348** and outer circumferential surface **344** shape, such that the rolling cutter **340** may smoothly rotate within the cutter pocket **330**.

Referring now to FIGS. **5** and **6**, a rolling cutter **540** may be retained within a cutter pocket **530** formed at the leading face **522** of a bit blade **520** using a back retainer **550** and a front retainer **560**, wherein the back retainer **550** is integral with the bit. The rolling cutter **540** has a cutting face **542**, an outer circumferential surface **544**, a cutting edge **546** formed at the intersection of the cutting face **542** and the outer circumferential surface **544**, and a back face **548**. As shown in FIG. **5**, the intersection between the back face **548** and the outer circumferential surface **544** of the rolling cutter **540** may form a substantially perpendicular intersection, such that the back face end of the rolling cutter has a cylindrical shape. However, according to other embodiments, such as shown in FIG. **6**, the back face **548** of the rolling cutter **540** may have a conical shape, wherein the intersection between the back face and outer circumferential surface forms an obtuse angle. In some embodiments of rolling cutters having a conical shaped back face, the transition from the back face to the outer circumferential surface may be gradual and continuous rather than forming an intersection angle.

The back retainer **550** is disposed adjacent to the back face **548** of the rolling cutter **540**, wherein the back retainer **550** protrudes partially into the rolling cutter **540** along a rotational axis R of the rolling cutter **540**, and a front retainer **560** may be disposed adjacent to the rolling cutter **540** on the leading face **522** of the blade **520**. Particularly, embodiments having a back retainer integrally formed with a blade may have the back retainer formed at on the back surface of the cutter pocket, such that when a rolling cutter is positioned adjacent to the back retainer, the rolling cutter is able to rotate about the back retainer and within the cutter pocket. Thus, in such embodiments, the shape of the integrally formed cutter pocket and back retainer substantially corresponds with the shape of the back face and outer circumferential surface of the rolling cutter. As shown in FIGS. **5** and **6**, the back retainer **550** may have a hemispherical shape protruding from the back surface of the cutter pocket. However, according to other embodiments, a back retainer may have other shapes, such as conical or cylindrical, wherein a correspondingly shaped hole formed in the back face of a rolling cutter may mate with and rotate about the back retainer shape.

For example, referring now to FIGS. **7** and **8**, a back retainer may be a cylindrical shaped pin. As shown, a rolling cutter **740** may be retained within a cutter pocket **730** formed at the leading face **722** of a bit blade **720** using a back retainer **750** and a front retainer **760**, wherein the back retainer **750** is a pin and a separate component from the blade. The rolling cutter **740** has a cutting face **742**, an outer circumferential surface **744**, a cutting edge **746** formed at the intersection of the cutting face **742** and the outer circumferential surface **744**, and a back face **748**. The back retainer **750** protrudes partially into the rolling cutter **740** along a rotational axis R of the rolling cutter **740**. As shown, the back retainer **750** mates with a corresponding shaped hole **749** formed in the back face **748** of the rolling cutter **740**, such that the rolling cutter **740** may rotate about the back retainer **750**.

Further, in embodiments having a back retainer that is a separate component from the blade, the back retainer may be disposed in a hole formed in the back surface of a cutter pocket. For example, as shown in FIGS. **7** and **8**, a back retainer **750** is disposed in a cutter pocket hole **739** formed in the back surface **738** of the cutter pocket **730**. The back retainer **750** may be attached to the cutter pocket hole **739** by means known in the art, such as brazing or interference fitting, so that the back retainer **750** does not rotate within the cutter pocket hole **739** as the rolling cutter **740** rotates about the back retainer **750**. Alternatively, in other embodiments, a back retainer may not be attached to the cutter pocket or the rolling cutter, such that the back retainer may rotate with respect to each of the cutter pocket and the rolling cutter. As shown, the shape of the back face **748** of the rolling cutter **740** mates with the shape of the back retainer **750** and the back surface **738** of the cutter pocket **730**. For example, the back face **748** of the rolling cutter **740** shown in FIG. **7** forms a conical shape having a hole **749** formed therein, wherein the back face **748** intersects with the outer circumferential surface **744** at an obtuse angle, and the back surface **738** of the cutter pocket **730** forms a substantially mating conical pocket, wherein the back surface **738** of the cutter pocket intersects the side surface of the cutter pocket **730** at substantially the same obtuse angle. As used herein, a “substantially mating” geometry includes a gap between the rolling cutter and the corresponding cutter pocket surface to allow the rolling cutter to rotate within the cutter pocket. In another example shown in FIG. **8**, the back face **748** intersects with the outer circumferential surface **744** at a substantially perpendicular angle, and the back surface **738** of the cutter pocket **730** intersects the side surface of the cutter pocket **730** at substantially the same perpendicular angle to form a substantially mating pocket.

Referring now to FIGS. **9-12**, a back retainer **950** having a cylindrical pin shape may be integrally formed with a blade **920**. Particularly, a rolling cutter **940** may be retained within a cutter pocket **930** formed at the leading face **922** of the blade **920** using a back retainer **950** and a front retainer **960**, wherein the back retainer **950** is a pin and integrally formed with the blade **920**. The rolling cutter **940** has a cutting face **942**, an outer circumferential surface **944**, a cutting edge **946** formed at the intersection of the cutting face **942** and the outer circumferential surface **944**, and a back face **948**. The back retainer **950** protrudes into a hole **949** formed in the back face **948** of the rolling cutter **940** along a rotational axis R of the rolling cutter **940**, such that the rolling cutter **940** may rotate about the back retainer **950**. Further, as shown in FIG. **9**, the back retainer **950** may extend a distance D substantially equal to the length of the hole **949**, such that the back retainer **950** mates with the rolling cutter hole **949**. In other embodiments, such as shown in FIGS. **10**, **13**, and **25** the back retainer may extend a partial length of a rolling cutter hole.

Particularly, FIG. **10** shows a cross-sectional view of a rolling cutter retained to a blade with a front retainer and a back retainer, wherein the back retainer extends a partial length of a hole formed in the rolling cutter. FIGS. **11** and **12** show perspective views of the embodiment shown in FIG. **10**. As shown, the rolling cutter **1040** has a cutting face **1042**, an outer circumferential surface **1044**, a cutting edge **1046** formed at the intersection of the cutting face **1042** and the outer circumferential surface **1044**, and a back face **1048**. The rolling cutter **1040** is retained within a cutter pocket **1030** formed at the leading face **1022** of a blade **1020** by a back retainer **1050** and a front retainer **1060**. The back retainer **1050** protrudes into a hole **1049** formed in the back face **1048** of the rolling cutter **1040** along a rotational axis R of the rolling cutter **1040**, such that the rolling cutter **1040** may rotate about the back retainer **1050**. As shown, the hole **1049** extends the entire length of the rolling cutter **1040** along the rotational axis R, from the back face **1048** to the cutting face **1042**. However, in other embodiments, the hole **1049** may extend less than the entire length of the rolling cutter. Further, the back retainer **1050** extends a partial length of the hole **1049**. Particularly, the back retainer **1050** may extend into the hole **1049** of the rolling cutter **1040** a distance D of at least 10 percent of the length of the rolling cutter **1040**, which may be less than or substantially equal to the length of the hole **1049** within the rolling cutter **1040**.

Additionally, as shown in FIGS. **10-12**, a front retainer **1060** may be disposed adjacent to the rolling cutter **1040** on the leading face **1022** of the blade **1020**. The front retainer **1060** has a retention end **1062** positioned adjacent to a portion of the cutting face **1042** of the rolling cutter **1040**, and an attachment end **1064** attached to a portion of the blade **1020**. A screw **1065** may be inserted through a hole in the attachment end **1064** of the front retainer **1060** and into a threaded cavity **1025** in the leading face **1022** of the blade **1020** below the cutter pocket **1030** in order to attach the front retainer **1060** to the blade **1020**. As shown, the threaded cavity may include a steel nut **1025** that has been infiltrated into the blade **1020**, wherein threads may be machined in the inside of the nut before or after infiltration.

FIG. **13** shows a cross-sectional view of another embodiment of a rolling cutter retained to a blade with a front retainer and a back retainer, wherein the back retainer extends a partial length of a hole formed in the rolling cutter. As shown, the rolling cutter **1340** has a cutting face **1342**, an outer circumferential surface **1344**, a cutting edge **1346** formed at the intersection of the cutting face **1342** and the outer circumferential surface **1344**, and a back face **1348**. The back retainer **1350** protrudes into a hole **1349** formed in the back face **1348** of the rolling cutter **1340** along a rotational axis R of the rolling cutter **1340**, such that the rolling cutter **1340** may rotate about the back retainer **1350**. As shown, the hole **1349** extends a partial length of the rolling cutter **1340** along the rotational axis R, from the back face **1348** of the rolling cutter **1340**. Further, the back retainer **1350** extends a partial length of the hole **1349**. Particularly, the back retainer **1350** may extend into the hole **1349** of the rolling cutter **1340** a distance D of at least 10 percent of the length of the rolling cutter **1340**, which may be less than or substantially equal to the length of the hole **1349** within the rolling cutter **1340**.

According to other embodiments of the present disclosure, a back retainer may be infiltrated into a cutter pocket. For example, as shown in FIG. **14**, a rolling cutter **1440** having a cutting face **1442**, an outer circumferential surface **1444**, a cutting edge **1446** formed at the intersection of the cutting face **1442** and the outer circumferential surface **1444**, and a back face **1448** is disposed in a cutter pocket **1430** formed in a blade **1420**. The rolling cutter **1440** is retained within the cutter pocket **1430** using a back retainer **1450** and a front retainer **1460**. The back retainer **1450** protrudes a distance into the back face **1448** of the rolling cutter **1440** along a rotational axis R of the rolling cutter **1440**, such that the rolling cutter **1440** may rotate about the back retainer **1450**. Further, a portion of the back retainer **1450** may extend adjacent to the back face **1448** of the rolling cutter **1440** rather than into the back face **1448**. The portion of the back retainer **1450** extending adjacent to the back face **1448** may extend above a top face **1423** of the blade **1420**. The back retainer **1450** may be infiltrated into the blade. Further, as shown, the back retainer **1450** has a conical shape protruding into the blade **1420** and a hemispherical shape protruding into the rolling cutter **1440**. However, in other embodiments, a back retainer may have other shapes.

Further, a back retainer may be made of the same material as the blade or a different material than the blade. According to embodiments of the present disclosure, a back retainer may be made of, for example, materials selected from a metal, a carbide material, such as tungsten carbide, hardened tool steel, ceramics, cubic boron nitride and diamond, such as polycrystalline diamond. For example, a back retainer may have diamond disposed at one or more interfacing surfaces with the rolling cutter, such as with the rolling cutter back face, to form a bearing surface. FIGS. **15** and **16** show some embodiments of a back retainer having diamond. Particularly, as shown in FIGS. **15** and **16**, a rolling cutter **1540** is retained within a cutter pocket **1530** using a back retainer **1550** and a front retainer **1560**. The back retainer **1550** protrudes a distance into the back face **1548** of the rolling cutter **1540** along a rotational axis R of the rolling cutter **1540**, such that the rolling cutter **1540** may rotate about the back retainer **1550**. The back retainer **1550** shown in FIG. **15** has a diamond band **1552** formed around the side surface of the back retainer. The back retainer shown in FIG. **16** has a polycrystalline diamond table **1554** formed at the end of the back retainer interfacing the rolling cutter **1540**. However, according to other embodiments, diamond may be formed at different positions on a back retainer.

Rolling cutters according to embodiments of the present disclosure may be formed of material including, for example, metal, carbides, such as tungsten carbide, tantalum carbide, or titanium carbide, nitrides, ceramics and diamond, such as polycrystalline diamond, or a combination thereof. For example, referring to FIGS. **17** and **18**, a perspective view and a cross-sectional view, respectively, is shown of a rolling cutter **1740** retained in a cutter pocket **1730** by a back retainer **1750** and a front retainer **1760**. The rolling cutter **1740** has a diamond table **1741** formed on a carbide substrate **1743**, wherein a diamond band **1745** is formed around the circumference of the substrate **1743**. The carbide substrate **1743** may include metal carbide grains, such as tungsten carbide, supported by a matrix of a metal binder. Various binding metals may be present in the substrate, such as cobalt, nickel, iron, alloys thereof, or mixtures, thereof. In a particular embodiment, the substrate may be formed of a sintered tungsten carbide composite structure of tungsten carbide and cobalt. However, it is known that various metal carbide compositions and binders may be used in addition to tungsten carbide and cobalt. Thus, references to the use of tungsten carbide and cobalt are for illustrative purposes only, and no limitation on the type of carbide or binder use is intended.

The diamond table **1741** may include polycrystalline diamond ("PCD") having a plurality of diamond particles bonded together to form a three-dimensional diamond network where a metallic phase, such as cobalt or other Group VIII metal, may be present in the interstitial regions disposed between the diamond particles. In particular, as used herein, "polycrystalline diamond" or "a polycrystalline diamond material" refers to this three-dimensional network or lattice of bonded together diamond grains. Specifically, the diamond to diamond bonding is catalyzed by a metal (such as cobalt) by a high temperature/high pressure process, whereby the metal remains in the regions between the particles. Thus, the metal particles added to the diamond particles may function as a catalyst and/or binder, depending on the exposure to diamond particles that can be catalyzed as well as the temperature/pressure conditions. Further, the polycrystalline diamond may be leached to remove (or render non-catalyzing) the catalyst/binder material from the diamond structure to form thermally stable polycrystalline diamond ("TSP"). One skilled in the art may appreciate that methods know in the art of forming TSP may be used to form the diamond table **1741**. Further, diamond composites, such as diamond/silicon or diamond/carbide composites, may be used to form the diamond table **1741**.

FIG. **19** shows a cross-sectional view of another embodiment having a rolling cutter **1940** formed of a carbide material and diamond, wherein the rolling cutter **1940** is retained within a cutter pocket **1930** by a front retainer **1960** and a back retainer **1950**. The rolling cutter **1930** may have more than one diamond table **1941** formed on a substrate **1943**, wherein the diamond table **1941** may form both the rolling cutter cutting face **1942** and the rolling cutter back face **1948**. Further, although the examples in FIGS. **17-19** include a rolling cutter formed of a carbide substrate having diamond layers formed thereon, rolling cutters of the present disclosure may include other combinations of materials.

According to embodiments of the present disclosure, disc springs may be retained with rolling cutters within a cutter pocket by a back retainer and front retainer. For example, referring to FIG. **20**, a cross-sectional view is shown of a disc spring **2070** disposed between a rolling cutter **2040** and a cutter pocket **2030** formed within a cutting tool blade **2020**. The rolling cutter **2030** is retained within the cutter pocket **2030** by a back retainer **2050** and a front retainer **2060**, wherein the rolling cutter has a cutting face **2042**, an outer circumferential surface **2044** and a back face **2048**. As shown, the disc spring **2070** is disposed at the back surface of the cutter pocket **2030**, adjacent to the back face **2048** of the rolling cutter **2040**. The back retainer **2050** extends through the disc spring **2070** and a distance into a hole **2049** formed in the rolling cutter **2040**, along the rotational axis R of the rolling cutter. However, according to other embodiments, a disc spring may be disposed within a hole formed in back face of a rolling cutter, between the back retainer and the rolling cutter. Advantageously, use of a disc spring in rolling cutter assemblies of the present disclosure may reduce contact area between the rolling cutter back face and the back surface of the cutter pocket. Additionally, the disc spring vibration allows the rolling cutter to move in an axial direction, which may assist in breaking up formation cuttings, as well as preventing cutting debris buildup. In particular, a disc spring may prevent cutting debris from packing between the cutting face of the rolling cutter and the front retainer. Further, the slight axial movement provided by the disc spring may inhibit the rolling cutter from being bound to the cutter pocket due to buildup of cutting debris within the gap between the rolling cutter outer diameter and the cutter pocket inner diameter.

Referring now to FIGS. **21-24**, embodiments of rolling cutters disclosed herein may also be retained within a cutter pocket by a back retainer, a front retainer and an outer shell. FIG. **21** shows a perspective view of a rolling cutter **2140** according to embodiments of the present disclosure, wherein the rolling cutter **2140** has a cutting face **2142**, an outer circumferential surface **2144**, a cutting edge **2146** formed at the intersection of the cutting face **2142** and the outer circumferential surface **2144**, a back face **2148**, and a rotational axis R extending through the length of the rolling cutter **2140**. A bevel may be formed at the cutting edge **2146** and/or at the intersection between the back face **2148** and the outer circumferential surface **2144**. As shown, the diameter of the outer circumferential surface **2144** proximate the back face **2148** is smaller than the diameter of the outer circumferential surface **2144** proximate the cutting face **2142**. Particularly, the diameter of the rolling cutter **2040** may decrease from the cutting face **2142** to the back face **2148**. The decrease in diameter may provide a mating portion of the rolling cutter to be inserted into an outer shell. FIG. **22** shows a perspective view of an outer shell **2180**, which may be positioned around a portion of a rolling cutter (shown in FIG. **21**), such that the rolling cutter may rotate within the outer shell **2180**, or alternatively, such that the rolling cutter and the outer shell may rotate together around a back retainer. As shown, the outer shell **2180** may have an inner surface **2182** and an outer surface **2184**, wherein the inner surface **2182** may be configured to mate with a portion of the outer circumferential surface of a rolling cutter.

FIG. **23** shows a cross-sectional view of a rolling cutter **2140** assembled within an outer shell **2180**. As shown, the inner surface **2182** may mate with a portion of the outer circumferential surface **2144** of the rolling cutter **2140**. Further, the outer shell **2180** may extend a distance D from the back face **2148** of the rolling cutter **2140**, such that a hole **2149** is formed adjacent to the back face **2148** and within the inner surface **2182** of the outer shell **2180**. However, according to other embodiments (such as shown in FIG. **28**), the outer shell may substantially align with the back face of the rolling cutter. FIG. **24** shows a cross-sectional view of the rolling cutter **2140** and the outer shell **2180** assembled in a cutter pocket **2130** formed in a cutting tool blade **2120**, wherein the rolling cutter **2140** is retained in the cutter pocket **2130** by the outer shell **2180**, a back retainer **2150** and a front retainer **2160**. As shown, the back retainer **2150** may be integrally formed with the blade **2120**, wherein the back retainer **2150** extends a distance into the hole **2149** formed by the rolling cutter **2140** and the outer shell **2180**. The outer shell may be formed of the same material as the rolling cutter or different material than the rolling cutter. For example, an outer shell may be formed of a metal carbide material or a combination of a carbide material and diamond, wherein a portion of the outer shell's inner surface is formed of diamond. According to other embodiments, an outer shell may be formed of other material combinations. Advantageously, some embodiments having an outer shell do not need the outer shell to be brazed or infiltrated to the blade. For example, according to some embodiments, the cutter pocket and the back retainer may be sufficient to retain the outer shell to the cutter pocket.

Referring now to FIGS. **27** and **28**, embodiments of rolling cutters disclosed herein may also be retained within a cutter pocket by a front retainer and an outer shell, without a back retention mechanism. FIGS. **27** and **28** show a cross-sectional view of a rolling cutter **2740** and an outer shell **2780** (which may be referred to as a sleeve) assembled in a cutter pocket **2730** formed in a cutting tool blade **2720**, wherein the rolling cutter **2740** is retained in the cutter pocket **2730** by the sleeve **2780** and a front retainer **2760**. The rolling cutter **2740** has a cutting face **2742**, an outer circumferential surface **2744**, a cutting edge **2746** formed at the intersection of the cutting face **2742** and the outer circumferential surface **2744**, a back face **2748**, and a rotational axis extending through the length of the rolling cutter **2740**. A bevel may be formed at the cutting edge **2746** and/or at the intersection between the back face **2748** and the outer circumferential surface **2744**. As shown, the diameter of the outer circumferential surface **2744** proximate the back face **2748** is smaller than the diameter of the outer circumferential surface **2744** proximate the cutting face **2742**. Particularly, the diameter of the rolling cutter **2740** may decrease from the cutting face **2742** to the back face **2748**. The decrease in diameter may provide a mating portion of the rolling cutter to be inserted into a sleeve. The sleeve may be positioned around a portion of the rolling cutter, such that the rolling cutter may rotate within the sleeve **2780**. The sleeve **2780** may have an inner surface **2782** and an outer surface **2784**, wherein the inner surface **2782** may be configured to mate with a portion of the outer circumferential surface of a rolling cutter. Further, the sleeve **2780** may have an outer diameter (measured between the outer surface **2784** of the sleeve) that is substantially equal to the diameter of the rolling cutter **2740** at the cutting face **2742**.

As shown in FIG. **27**, the sleeve **2780** may extend a distance D from the back face **2748** of the rolling cutter **2740**, such that a hole **2749** is formed adjacent to the back face **2748** and within the inner surface **2782** of the sleeve **2780**. However, according to other embodiments, such as shown in FIG. **28**, an end of the sleeve **2780** may substantially align with the back face **2748** of the rolling cutter **2740**. In such embodiments, the back face **2748** and the end of the sleeve **2780** may interface with a back surface of the cutter pocket **2730**.

According to some embodiments of the present disclosure, a rolling cutter may be retained within a cutter pocket by a side retention mechanism, a front retainer and a sleeve. For example, FIG. **29** shows a cross-sectional view of the rolling cutter **2940** and a sleeve **2980** assembled in a cutter pocket **2930** formed in a cutting tool blade **2920**, wherein the rolling cutter **2940** is retained in the cutter pocket **2930** by the sleeve **2980**, a side retention mechanism **2950** and a front retainer **2960**. The rolling cutter **2940** has a cutting face **2942**, an outer circumferential surface **2944**, a cutting edge **2946** formed at the intersection of the cutting face **2942** and the outer circumferential surface **2944**, a back face **2948**, and a rotational axis extending through the length of the rolling cutter **2940**. The sleeve **2980** has an inner surface **2982** and an outer surface **2984**. The side retention mechanism **2950** is disposed between the sleeve **2980** and the rolling cutter **2940** to axially retain the rolling cutter within the sleeve. As shown, the side retention mechanism **2950** may include at least one ball **2951** disposed between a circumferential groove **2941** formed around the outer circumferential surface **2944** of the rolling cutter **2940** and a corresponding groove **2981** formed around the inner surface **2982** of the sleeve **2980**. However, other forms of side retention mechanisms may be used between the sleeve and rolling cutter side walls to axially retain the rolling cutter within the sleeve. For example, a protrusion may be formed around the outer circumferential surface of the rolling cutter and a corresponding groove may be formed around the inner surface of the sleeve and/or a groove may be formed around the outer circumferential surface of the rolling cutter and a corresponding protrusion may be formed around the inner surface of the sleeve. In some embodiments, side retention mechanisms may be integrally formed with the rolling cutter and/or the sleeve. In other embodiments, side retention mechanisms may be separate components from the sleeve and/or rolling cutter.

In other embodiments, a rolling cutter may be retained within a cutter pocket without using a front retainer. In such embodiments, a rolling cutter may be retained within a cutter pocket by at least two of a side retention mechanism, a sleeve, and a back retention mechanism. For example, according to some embodiments, a rolling cutter may be retained within a cutter pocket using a combination of a side retention mechanism and a sleeve. The side retention mechanism, such as those described above, may retain the rolling cutter axially within the sleeve, and the sleeve may retain the rolling cutter from being radially dislodged from the cutter pocket. In some embodiments, a rolling cutter may be retained within a cutter pocket using a combination of a side retention mechanism, such as described above, and a back retention mechanism, such as one described above. The side retention mechanism may retain the rolling cutter axially within the sleeve, and the back retention mechanism may retain the rolling cutter from being radially dislodged from the cutter pocket.

Methods of manufacturing embodiments according to the present disclosure may include, for example, forming a bit body having a threaded pin end and a cutting end, wherein at least one blade is formed on the cutting end, and wherein the blade has a plurality of cutter pockets formed therein. A rolling cutter may then be placed into at least one of the plurality of cutter pockets, adjacent to a back retainer. An attachment end of a front retainer may be attached to a portion of the blade, such that a retention end of the front retainer covers a portion of a cutting face of the rolling cutter. The back retainer may be integrally formed with the bit body and extends from a back surface of the at least one cutter pocket. Alternatively, the back retainer may be a separate component from the blade, disposed within a cutter pocket hole in a back surface of the at least one cutter pocket. Further, the front retainer may be attached to a blade by inserting the attachment end of the front retainer into a cavity formed in the blade. According to some embodiments, the cavity may be threaded, wherein the step of inserting the attachment end includes screwing the attachment end into the threaded cavity.

Advantageously, by using a back retainer and front retainer according to the present disclosure, a rolling cutter may be retained within a cutter pocket having a decreased amount of cutter pocket coverage, which may also provide better cleaning of the cutter pocket during drilling. For example, embodiments having decreased cutter pocket coverage may include cutter pockets that extend less than 180 degrees and greater than 120 degrees around a portion of the outer circumferential surface of a rolling cutter. Decreased cutter pocket coverage may allow for a wider range of rolling cutter sizes, such as rolling cutters with larger diameters and/or shorter lengths than conventional cutters, and may match the amount of cutter exposure of standard fixed cutters, including ones with low back rake angles. Further, by using a back retainer and front retainer according to the present disclosure to retain a rolling cutter within a cutter pocket rather than the conventional brazing process, high processing temperatures may be avoided. Thus, harmful thermal exposure to embodiments having a polycrystalline diamond layer or thermally stable polycrystalline diamond layer may be reduced.

Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from this invention. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims.

What is claimed is:

1. A drill bit, comprising:

a bit body;

a plurality of blades extending radially from the bit body, wherein each blade comprises a leading face and a trailing face;

a plurality of cutter pockets disposed on the plurality of blades;

at least one rolling cutter, wherein each rolling cutter is disposed in one of the cutter pockets, and wherein each rolling cutter comprises a cutting face, a cutting edge, an outer circumferential surface, and a back face;

a back retainer disposed adjacent to the back face, wherein the back retainer protrudes partially into the rolling cutter along a rotational axis of the rolling cutter; and

a front retainer disposed adjacent to the at least one rolling cutter on the leading face of the blade, wherein each front retainer comprises:

a retention end, wherein the retention end is positioned adjacent to a portion of the cutting face of each rolling cutter; and

an attachment end, wherein the attachment end is attached to a leading face of the blade adjacent to the one of the cutter pockets.

2. The drill bit of claim **1**, wherein the back retainer is a ball.

3. The drill bit of claim **1**, wherein the back retainer is a pin.

4. The drill bit of claim **1**, wherein the back retainer is integral with the bit body.

5. The drill bit of claim **1**, further comprising:

a screw; and

at least one threaded cavity formed within the leading face of the blade below each cutter pocket,

wherein the screw is inserted through a hole in the attachment end of the front retainer and into the threaded cavity in the blade, thereby attaching the attachment end to a portion of the leading face of the blade.

6. The drill bit of claim **5**, wherein the threaded cavity comprises a threaded nut brazed within a cavity.

7. The drill bit of claim **1**, wherein the back retainer extends into the rolling cutter a distance less than or equal to an entire length of the rolling cutter.

8. The drill bit of claim **1**, wherein the rolling cutter further comprises a polycrystalline diamond table and wherein the polycrystalline diamond table forms the cutting face.

9. The drill bit of claim **1**, wherein the back face of the rolling cutter has a conical shape.

10. The drill bit of claim **1**, wherein the front retainer comprises carbide.

11. The drill bit of claim **1**, wherein the back retainer comprises diamond.

12. The drill bit of claim **1**, further comprising a disc spring positioned between the cutter pocket and the back face of the rolling cutter.

13. The drill bit of claim **1**, further comprising a sleeve disposed around the rolling cutter and around the back retainer.

14. The drill bit of claim **1**, wherein the attachment end of the front retainer forms a portion of the cutter pocket.

15. The drill bit of claim **1**, wherein the cutter pocket extends less than 180 degrees and greater than 120 degrees around the circumference of at least a portion of the at least one rolling cutter.

16. A method of manufacturing a drill bit, comprising:
forming a bit body comprising a threaded pin end and a cutting end, wherein at least one blade having a blade face is formed on the cutting end, and wherein the blade has a plurality of cutter pockets formed therein;
placing a rolling cutter into at least one of the plurality of cutter pockets, adjacent to a back retainer, wherein the rolling cutter comprises a substrate and a cutting face; and
attaching an attachment end of a front retainer to a portion of the blade face adjacent to the at least one of the plurality of cutter pockets, such that a retention end of the front retainer covers a portion of the cutting face.

17. The method of claim **16**, wherein the back retainer is integral with the bit body and extends from a back surface of the at least one cutter pocket.

18. The method of claim **16**, wherein the back retainer is disposed within a cutter pocket hole in a back surface of the at least one cutter pocket.

19. The method of claim **16**, wherein the blade has at least one cavity formed therein and wherein the step of attaching comprises:
inserting the attachment end of the front retainer into the cavity.

20. The method of claim **19**, wherein the at least one cavity is threaded, and wherein the step of inserting the attachment end comprises screwing the attachment end into the threaded cavity.

21. The method of claim **16**, further comprising disposing a sleeve around the rolling cutter and the back retainer.

22. A drill bit, comprising:
a bit body;
a plurality of blades extending radially from the bit body, wherein each blade comprises a leading face and a trailing face;
a plurality of cutter pockets disposed on the plurality of blades;
at least one rolling cutter partially surrounded by a sleeve, wherein each rolling cutter and sleeve are disposed in one of the cutter pockets; and
a front retainer disposed adjacent to the at least one rolling cutter on the leading face of the blade and a distance apart from the sleeve, wherein each front retainer comprises:
a retention end, wherein the retention end is positioned adjacent to a portion of a cutting face of each rolling cutter; and
an attachment end, wherein the attachment end is attached to a portion of the leading face of the blade adjacent to the one of the cutter pockets.

23. The drill bit of claim **22**, wherein the sleeve has an outer diameter substantially equal to a diameter of the cutting face of the rolling cutter.

24. The drill bit of claim **22**, further comprising a side retention mechanism between the sleeve and the rolling cutter.

25. The drill bit of claim **24**, wherein the side retention mechanism comprises at least one ball disposed between a circumferential groove formed around the rolling cutter and a corresponding groove formed around an inner wall of the sleeve.

26. The drill bit of claim **24**, wherein the side retention mechanism is integrally formed with the sleeve.

27. The drill bit of claim **22**, wherein a back face of the rolling cutter is substantially aligned with an end surface of the sleeve.

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